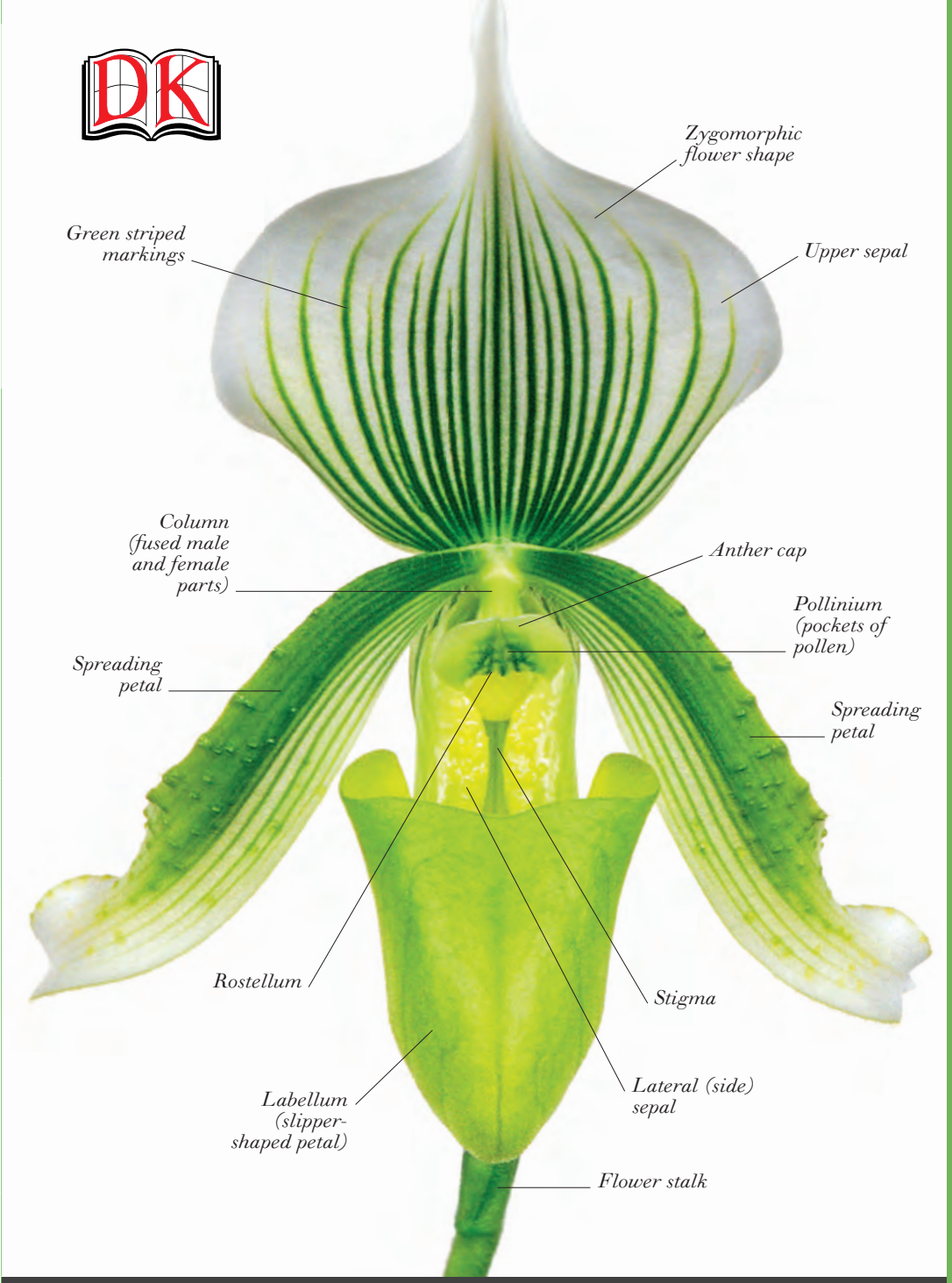

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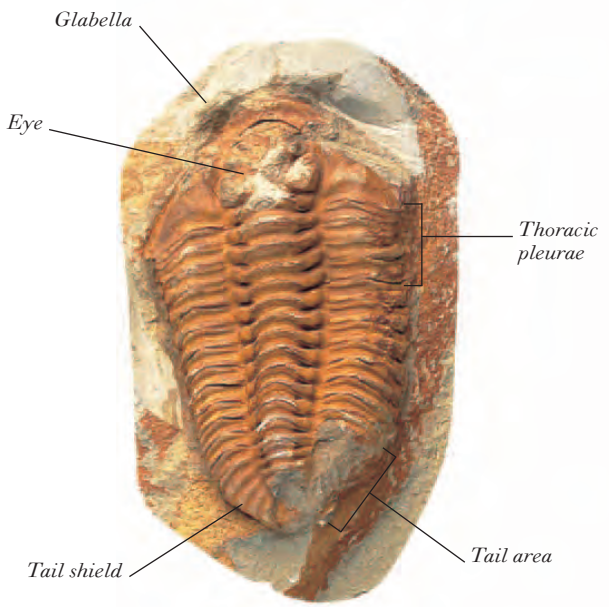

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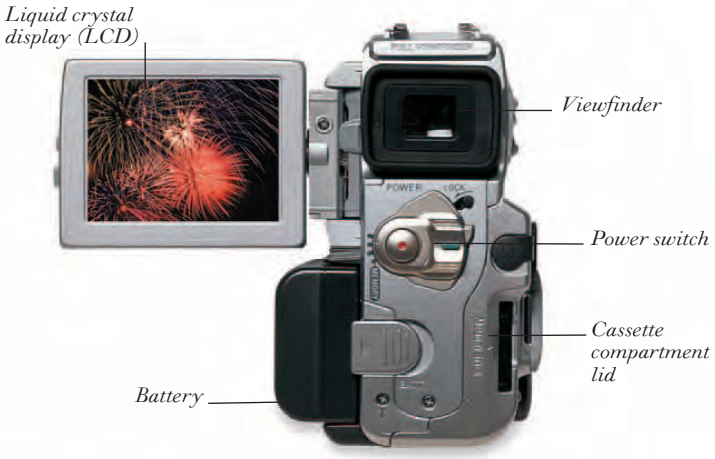
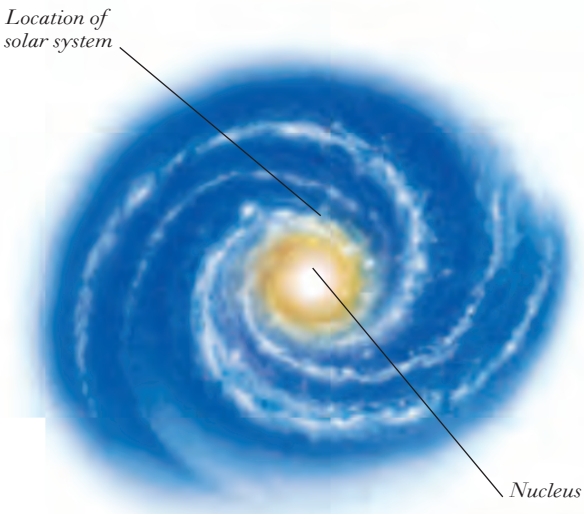
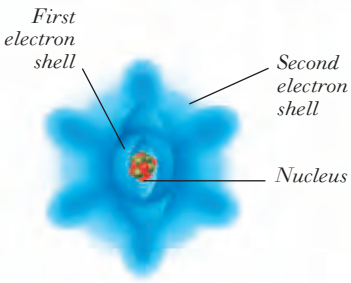


OVERHEAD VIEW OF OUR GALAXY





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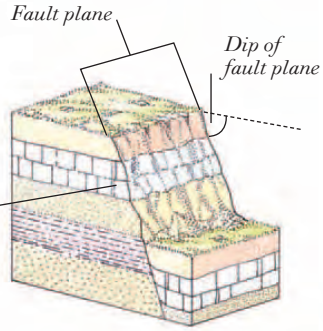

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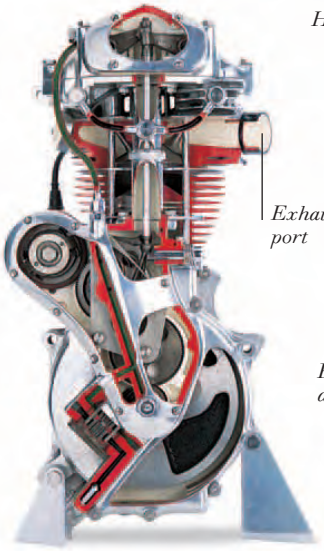

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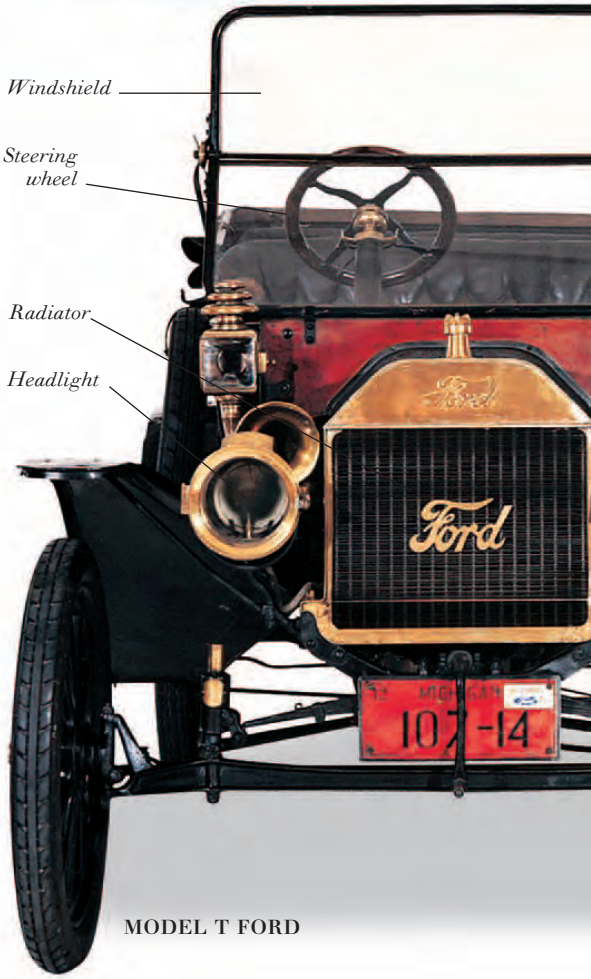

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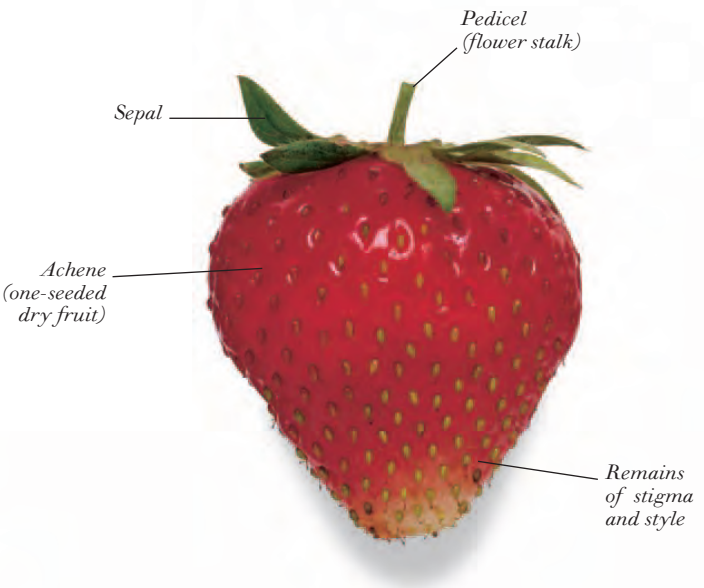

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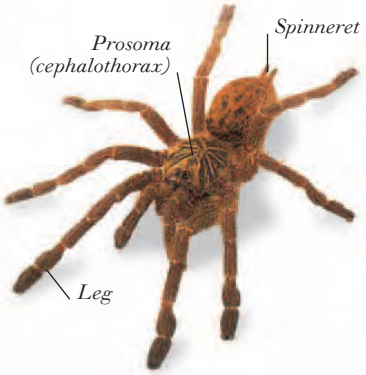

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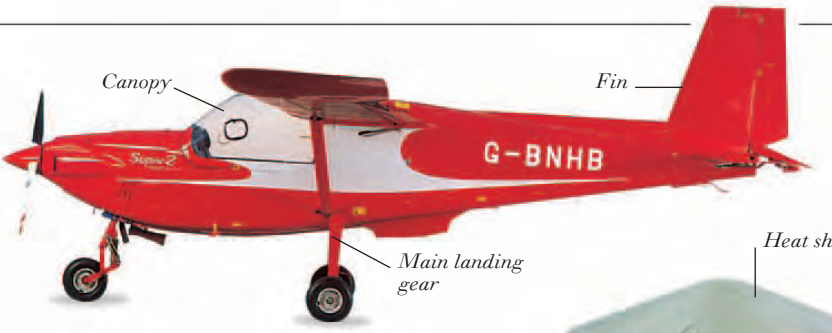


SIDE VIEW OF ARV SUPER 2 AIRPLANE

CONTENTS

INTRODUCTION 6

THE UNIVERSE 8

PREHISTORIC EARTH 54

PLANTS 110

ANIMALS 164

THE HUMAN BODY 208

GEOLOGY, GEOGRAPHY, AND METEOROLOGY 262

PHYSICS AND CHEMISTRY 304

RAIL AND ROAD 322

SEA AND AIR 370

THE VISUAL ARTS 428

ARCHITECTURE 456

MUSIC 500

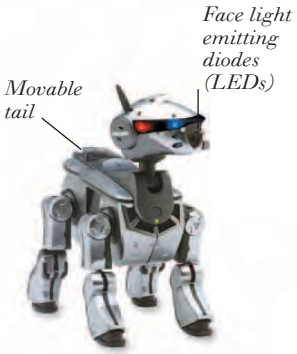
SPORTS 522

THE MODERN WORLD 564

APPENDIX 616

INDEX 624

FOUNTAIN PEN AND INK



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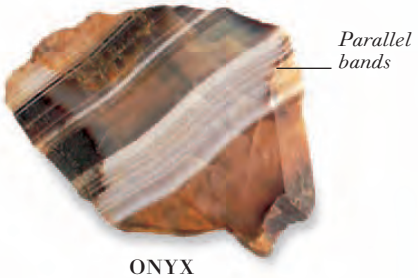

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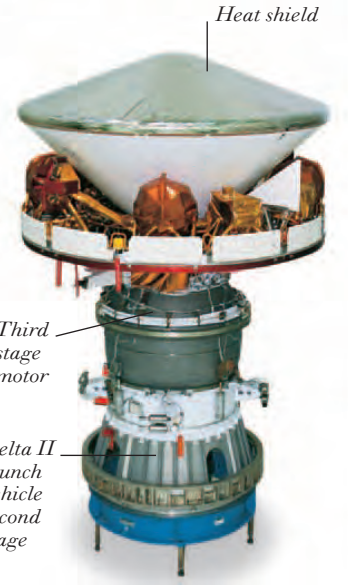

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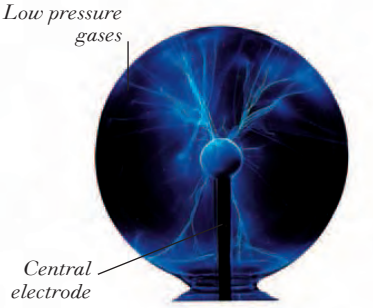
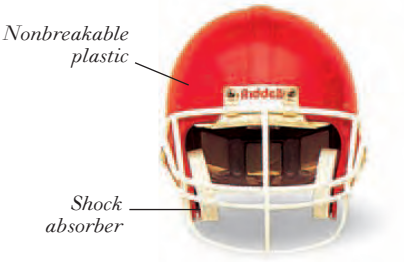


BALL CONTAINING HIGH TEMPERATURE GAS (PLASMA)



FOOTBALL HELMET

Introduction

THE VISUAL DICTIONARY is a completely new kind of reference book. It provides a link between pictures and words in a way that no ordinary dictionary ever has. Most dictionaries simply tell you what a word means, but the *VISUAL DICTIONARY* shows you—through a combination of detailed annotations, explicit photographs, and illustrations. In the *VISUAL DICTIONARY*, pictures define the annotations around them. You do not read definitions of the annotated words, you see them. The highly accessible format of the *VISUAL DICTIONARY*, the thoroughness of its annotations, and the range of its subject matter make it a unique and helpful reference tool.

How to use the VISUAL DICTIONARY

You will find the *VISUAL DICTIONARY* simple to use. Instead of being organized alphabetically, it is divided by subject into 14 sections—THE UNIVERSE, PREHISTORIC EARTH, PLANTS, ANIMALS, THE HUMAN BODY, etc. Each section begins with a table of contents listing the major entries within that section. For example, The Visual Arts section has entries on *Drawing*, *Tempera*, *Fresco*, *Oils*, *Watercolor*, *Pastels*, *Acrylics*, *Calligraphy*, *Printmaking*, *Mosaic*, and *Sculpture*. Every entry has a short introduction explaining the purpose of the photographs and illustrations, and the significance of the annotations.

If you know what something looks like, but don't know its name, find the term you need by turning to the annotations surrounding the pictures; if you know a word, but don't know what it refers to, use the comprehensive index to direct you to the appropriate page.

Suppose that you want to know what the bone at the end of your little finger is called. With a standard dictionary, you wouldn't know where to begin. But with the *VISUAL DICTIONARY* you simply turn to the entry called *Hands*—within THE HUMAN BODY section—where you will find four fully annotated, color photographs showing the skin, muscles, and bones of the human hand. In this entry you will quickly find that the bone you are searching for is called the distal phalanx, and for good measure you will discover that it is attached to the middle phalanx by the distal interphalangeal joint.

Perhaps you want to know what a catalytic converter looks like. If you look up "catalytic converter" in an ordinary dictionary, you will be told what it is and possibly what it does—but you will not be able to tell what shape it is or what it is made of. However, if you look up "catalytic converter" in the index of the *VISUAL DICTIONARY*, you will be directed to the *Modern engines* entry on page 344—where the introduction gives you basic information about what a catalytic converter is—and to page 350—where there is a spectacular exploded-view photograph of the mechanics of a Renault Clio. From these pages you will find out not only what a catalytic converter looks like, but also that it is attached at one end to an exhaust pipe and at the other to a muffler.

Whatever it is that you want to find a name for, or whatever name you want to find a picture for, you will find it quickly and easily in the *VISUAL DICTIONARY*. Perhaps you need to know where the vamp on a shoe is; or how to tell obovate and lanceolate leaves apart; or what a spiral galaxy looks like; or whether birds have nostrils. With the *VISUAL DICTIONARY* at hand, the answers to each of these questions, and thousands more, are readily available.

The *VISUAL DICTIONARY* does not just tell you what the names of the different parts of an object are. The photographs, illustrations, and annotations are all specially arranged to help you understand which parts relate to one another and how objects function.

With the *VISUAL DICTIONARY* you can find in seconds the words or pictures that you are looking for; or you can simply browse through the pages of the book for your own pleasure. The *VISUAL DICTIONARY* is not intended to replace a standard dictionary or conventional encyclopedia, but is instead a stimulating and valuable companion to ordinary reference volumes. Giving you instant access to the language that is used by astronomers and architects, musicians and mechanics, scientists and sportspeople, it is the ideal reference book for specialists and generalists of all ages.

Sections of the VISUAL DICTIONARY

The 14 sections of the *VISUAL DICTIONARY* contain a total of more than 30,000 terms, encompassing a wide range of topics:

- In the first section, **THE UNIVERSE**, spectacular photographs and illustrations are used to show the names of the stars and planets and to explain the structure of solar systems, galaxies, nebulae, comets, and black holes.

- **PREHISTORIC EARTH** tells the story in annotations of how our own planet has evolved since its formation. It includes examples of prehistoric flora and fauna, and fascinating dinosaur models—some with parts of the body stripped away to show anatomical sections.

- **PLANTS** covers a huge range of species—from the familiar to the exotic. In addition to the color photographs of plants included in this section, there is a series of micrographic photographs illustrating plant details—such as pollen grains, spores, and cross-sections of stems and roots—in close-up.

- In the **ANIMALS** section, skeletons, anatomical diagrams, and different parts of animals' bodies have been meticulously annotated. This section provides a comprehensive guide to the vocabulary of zoological classification and animal physiology.

- The structure of the human body, its parts, and its systems are presented in **THE HUMAN BODY**. The section includes lifelike, three-dimensional models and the latest false-color images. Clear and authoritative annotations indicate the correct anatomical terms.

- **GEOLOGY, GEOGRAPHY, AND METEOROLOGY** describes the structure of the Earth—from the inner core to the exosphere—and the physical phenomena—such as volcanoes, rivers, glaciers, and climate—that shape its surface.

- **PHYSICS AND CHEMISTRY** is a visual journey through the fundamental principles underlying the physical universe, and provides the essential vocabulary of these sciences.

- In **RAIL AND ROAD**, a wide range of trains, trams and buses, cars, bicycles, and motorcycles are described. Exploded-view photographs show mechanical details with striking clarity.

- **SEA AND AIR** gives the names for hundreds of parts of ships and airplanes. The section includes civil and fighting craft, both historical and modern.

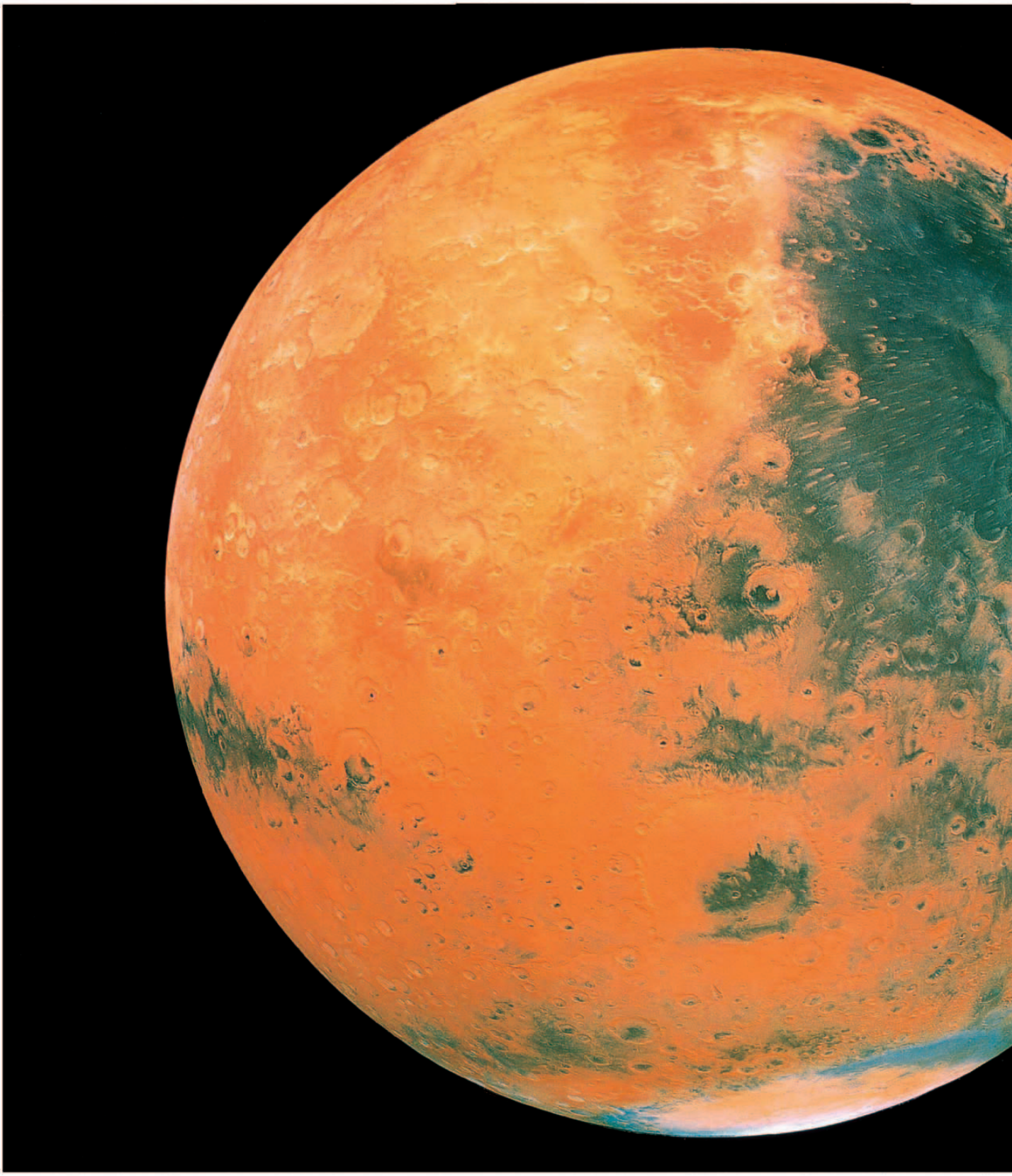
- **THE VISUAL ARTS** shows the equipment and materials used by painters, sculptors, printers, and other artists. Well-known compositions have been chosen to illustrate specific artistic techniques and effects.

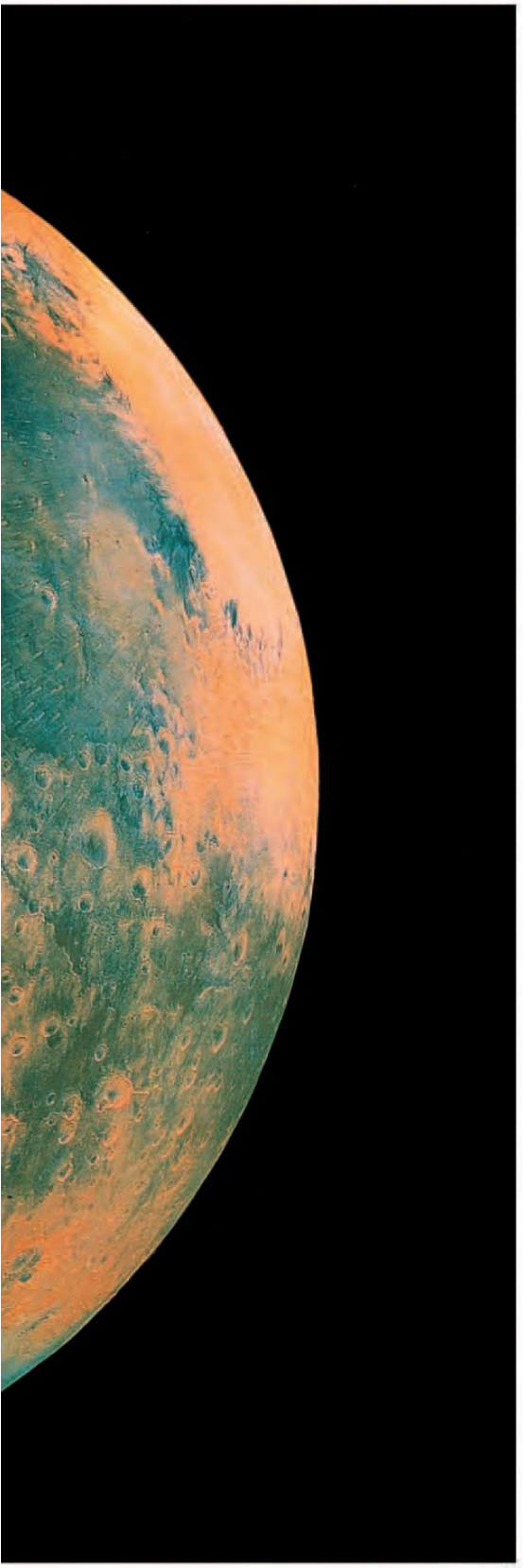
- **ARCHITECTURE** includes photographs of exemplary architectural models and illustrates dozens of additional features such as columns, domes, and arches.

- **MUSIC** provides a visual introduction to the special language of music and musical instruments. It includes clearly annotated photographs of each of the major groups of traditional instruments—brass, woodwind, strings, and percussion—together with modern electronic instruments.

- The **SPORTS** section is a guide to the playing areas, formations, equipment, and techniques needed for many of today's most popular sports.

- In **THE MODERN WORLD**, items that are a familiar part of our daily lives are taken apart to reveal their inner workings and give access to the language used by their manufacturers. It also includes systems and concepts, such as the internet, that increasingly influence our 21st century world.



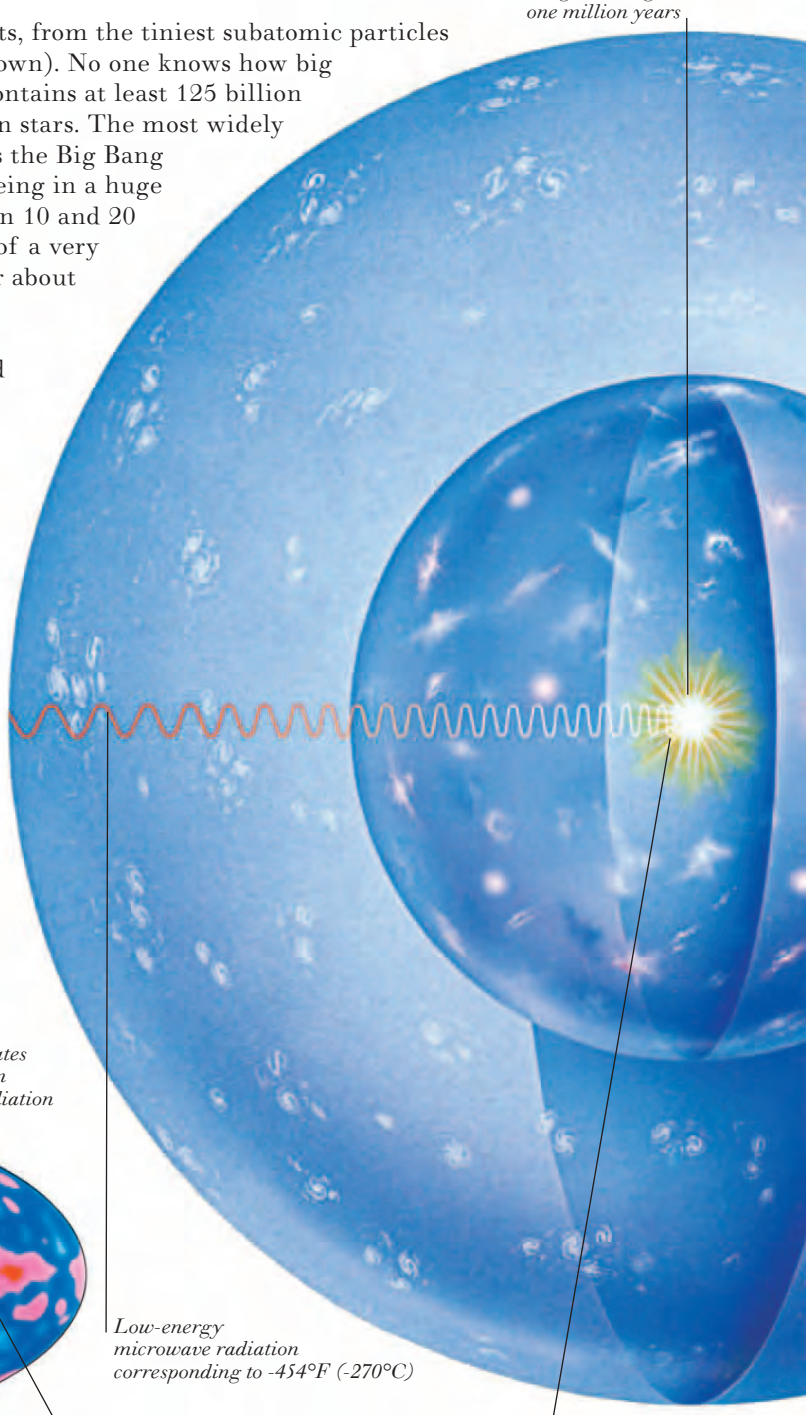


The Universe

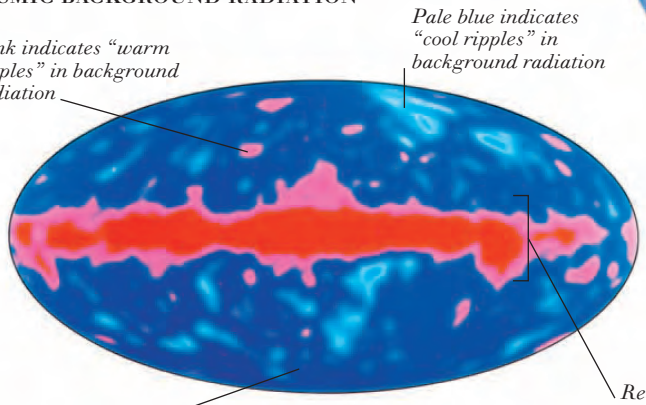
Anatomy of the Universe 10
Galaxies 12
The Milky Way 14
Nebulae and Star Clusters 16
Stars of Northern Skies 18
Stars of Southern Skies 20
Stars 22
Small Stars 24
Massive Stars 26
Neutron Stars and Black Holes 28
The Solar System 30
The Sun 32
Mercury 34
Venus 36
The Earth 38
The Moon 40
Mars 42
Jupiter 44
Saturn 46
Uranus 48
Neptune and Pluto 50
Asteroids, Comets, and Meteoroids 52

Anatomy of the universe

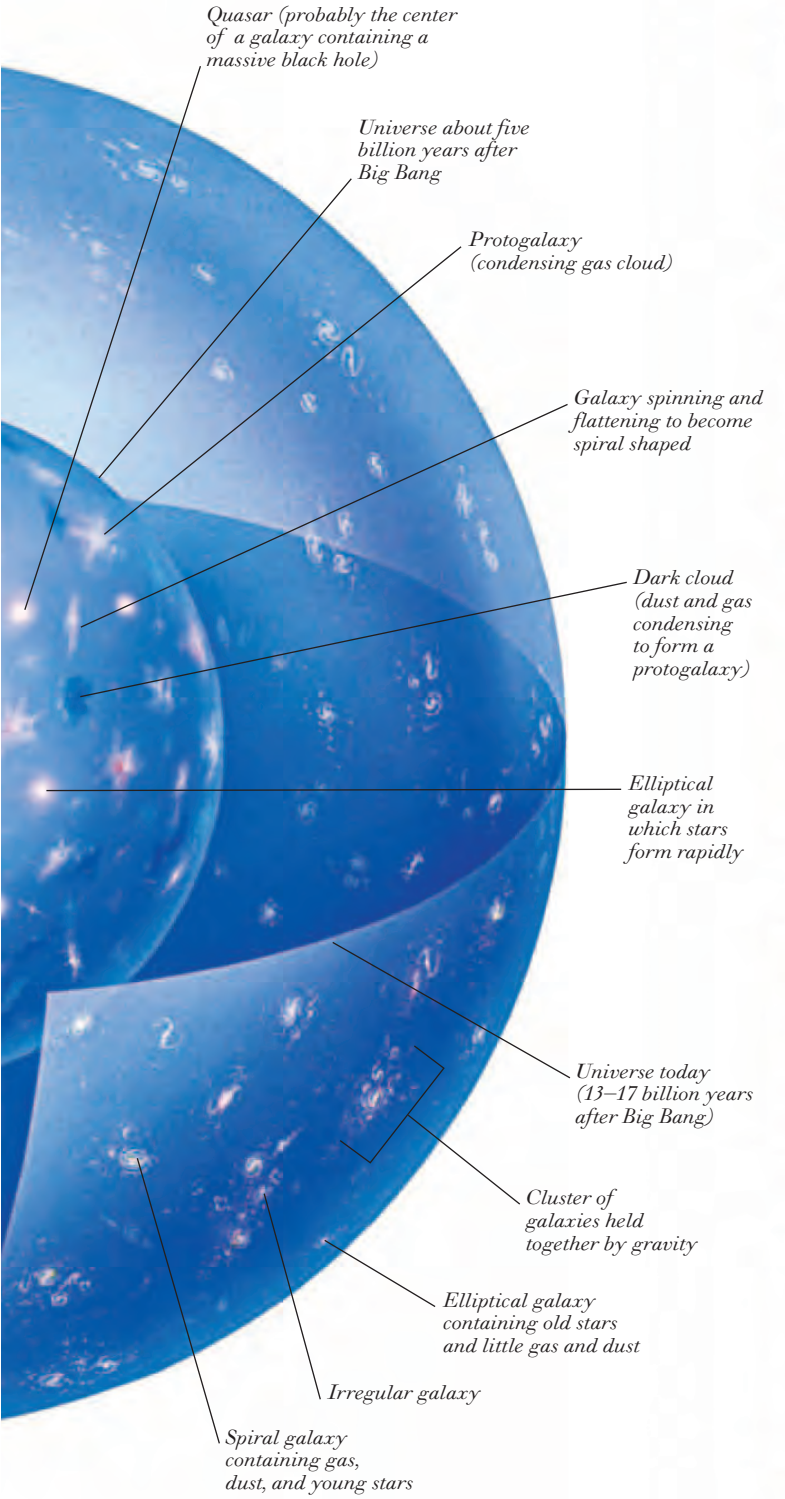
THE UNIVERSE CONTAINS EVERYTHING that exists, from the tiniest subatomic particles to galactic superclusters (the largest structures known). No one knows how big the universe is, but astronomers estimate that it contains at least 125 billion galaxies, each comprising an average of 100 billion stars. The most widely accepted theory about the origin of the universe is the Big Bang theory, which states that the universe came into being in a huge explosion—the Big Bang—that took place between 10 and 20 billion years ago. The universe initially consisted of a very hot, dense fireball of expanding, cooling gas. After about one million years, the gas began to condense into localized clumps called protogalaxies. During the next five billion years, the protogalaxies continued condensing, forming galaxies in which stars were being born. Today, billions of years later, the universe as a whole is still expanding, although there are localized areas in which objects are held together by gravity; for example, many galaxies are found in clusters. The Big Bang theory is supported by the discovery of faint, cool background radiation coming evenly from all directions. This radiation is believed to be the remnant of the radiation produced by the Big Bang. Small "ripples" in the temperature of the cosmic background radiation are thought to be evidence of slight fluctuations in the density of the early universe, which resulted in the formation of galaxies. Astronomers do not yet know if the universe is "closed," which means it will eventually stop expanding and begin to contract, or if it is "open," which means it will continue expanding forever.



FALSE-COLOR MICROWAVE MAP OF COSMIC BACKGROUND RADIATION

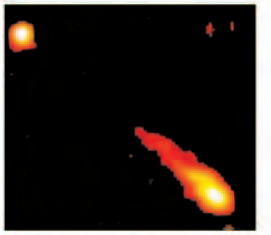


ORIGIN AND EXPANSION OF THE UNIVERSE



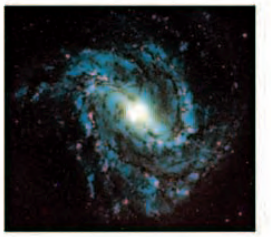
OBJECTS IN THE UNIVERSE

CLUSTER OF GALAXIES IN VIRGO



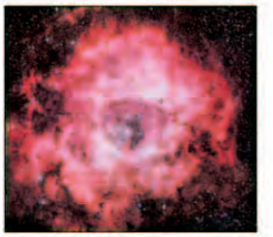
FALSE-COLOR IMAGE OF 3C273 (QUASAR)

NGC 4406 (ELLIPTICAL GALAXY)

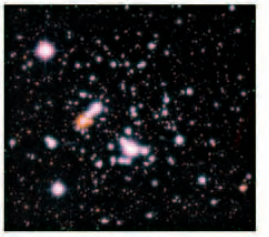


NGC 5236 (BARRED SPIRAL GALAXY)

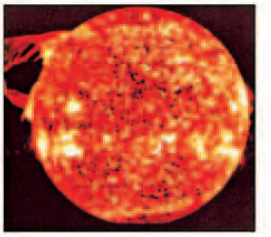
NGC 6822 (IRREGULAR GALAXY)



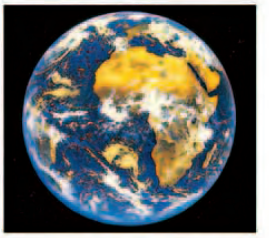
THE ROSETTE NEBULA (EMISSION NEBULA)



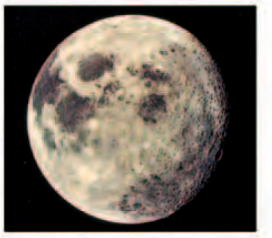
THE JEWEL BOX (STAR CLUSTER)



THE SUN (MAIN SEQUENCE STAR)



EARTH



THE MOON

Galaxies

SOMBRERO, A SPIRAL GALAXY

A GALAXY IS A HUGE MASS OF STARS, nebulae, and interstellar material. The smallest galaxies contain about 100,000 stars, while the largest contain up to 3 trillion stars. There are three main types of galaxy, classified according to their shape: elliptical, which are oval shaped; spiral, which have arms spiraling outward from a central bulge (those whose arms spiral from a bar-shaped bulge are called spirals); and irregular, which have no obvious shape. Sometimes, the shape of a galaxy is distorted by a collision with another galaxy. Quasars (quasi-stellar objects) are thought to be galactic nuclei but are so far away that their exact nature is still uncertain. They are compact, highly luminous objects in the outer reaches of the known universe: while the farthest known "ordinary" galaxies are about 12 billion light-years away, the farthest known quasar is about 13 billion light-years away. Active galaxies, such as Seyfert galaxies and radio galaxies, emit intense radiation. In a Seyfert galaxy, this radiation comes from the galactic nucleus; in a radio galaxy, it also comes from huge lobes on either side of the galaxy. The radiation from active galaxies and quasars is thought to be caused by material falling into central black holes (see pp. 28-29).

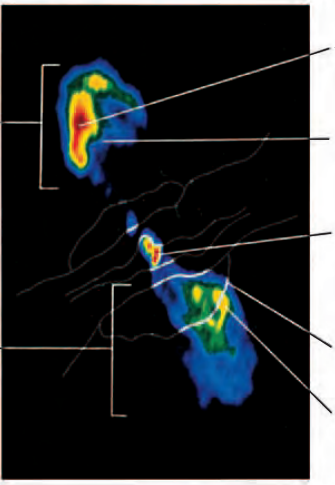
OPTICAL IMAGE OF NGC 4486 (ELLIPTICAL GALAXY)

OPTICAL IMAGE OF LARGE MAGELLANIC CLOUD (IRREGULAR GALAXY)

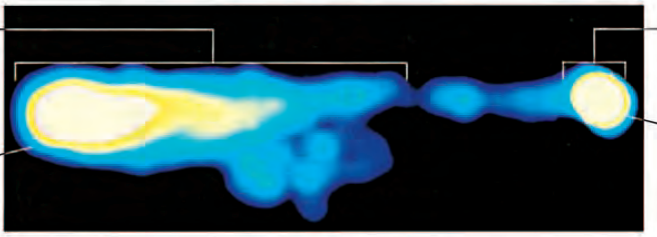
OPTICAL IMAGE OF NGC 2997 (SPIRAL GALAXY)

OPTICAL IMAGE OF CENTAURUS A (RADIO GALAXY)

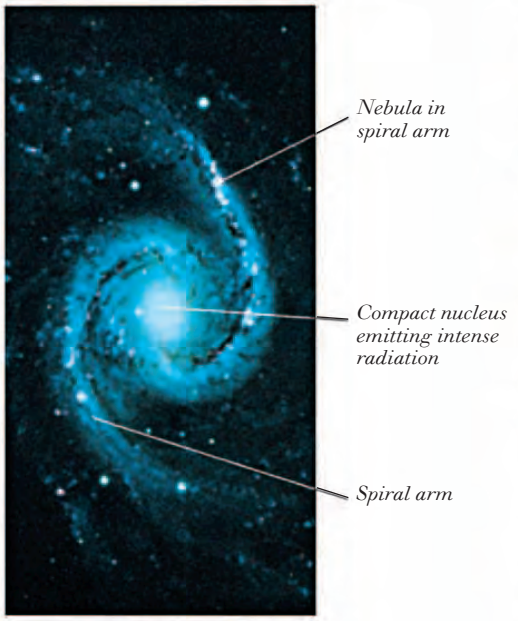
FALSE-COLOR RADIO IMAGE OF CENTAURUS A



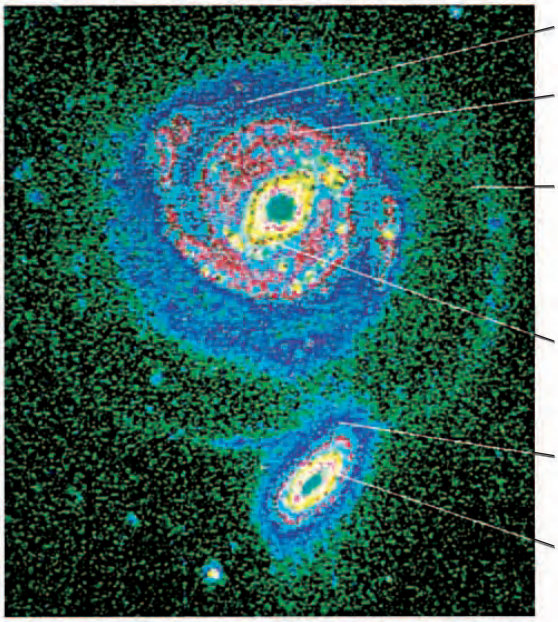
FALSE-COLOR RADIO IMAGE OF 3C 273 (QUASAR)



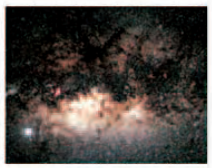
OPTICAL IMAGE OF NGC 1566 (SEYFERT GALAXY)



FALSE-COLOR OPTICAL IMAGE OF NGC 5754 (TWO COLLIDING GALAXIES)



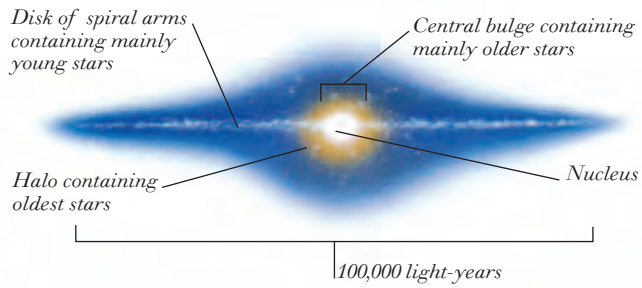
The Milky Way



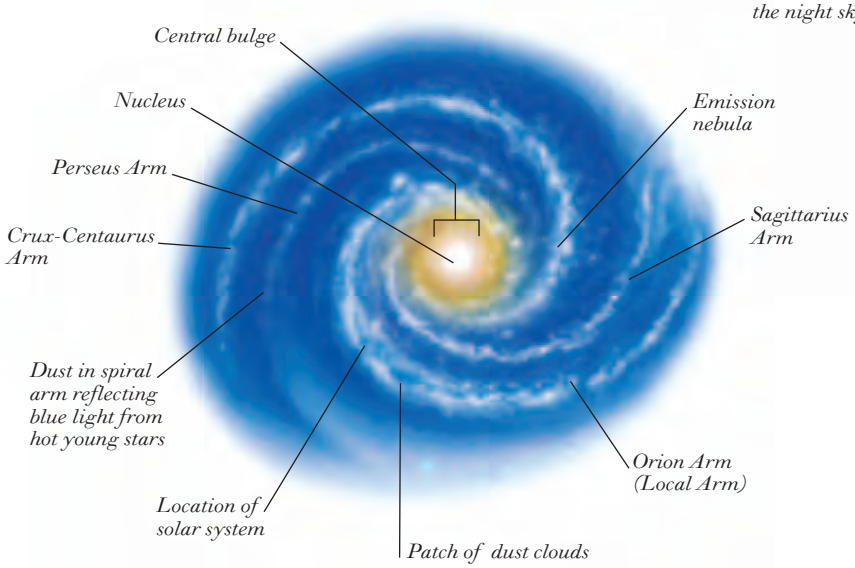
VIEW TOWARD GALACTIC CENTER

THE MILKY WAY IS THE NAME GIVEN TO THE FAINT BAND OF LIGHT that stretches across the night sky. This light comes from stars and nebulae in our galaxy, known as the Milky Way Galaxy or simply as "the Galaxy." The Galaxy is believed to be a barred spiral, with a dense central bar of stars encircled by four arms spiraling outward and surrounded by a less dense halo. We cannot see the spiral shape because the solar system is in one of the spiral arms, the Orion Arm (also called the Local Arm). From our position, the center of the Galaxy is completely obscured by dust clouds; as a result, optical maps give only a limited view of the Galaxy. However, a more complete picture can be obtained by studying radio, infrared, and other radiation. The central part of the Galaxy is relatively small and dense and contains mainly older red and yellow stars. The halo is a less dense region in which the oldest stars are situated; some of these stars are as old as the Galaxy itself (possibly 13 billion years). The spiral arms contain main sequence stars and hot, young, blue stars, as well as nebulae (clouds of dust and gas inside which stars are born). The Galaxy is vast, about 100,000 light-years across (a light-year is about 5,870 billion miles/9,460 billion km); in comparison, the solar system seems small, at about 12 light-hours across (about 8 billion miles/13 billion km). The entire Galaxy is rotating in space, although the inner stars travel faster than those farther out. The Sun, which is about two-thirds out from the center, completes one lap of the Galaxy about every 220 million years.

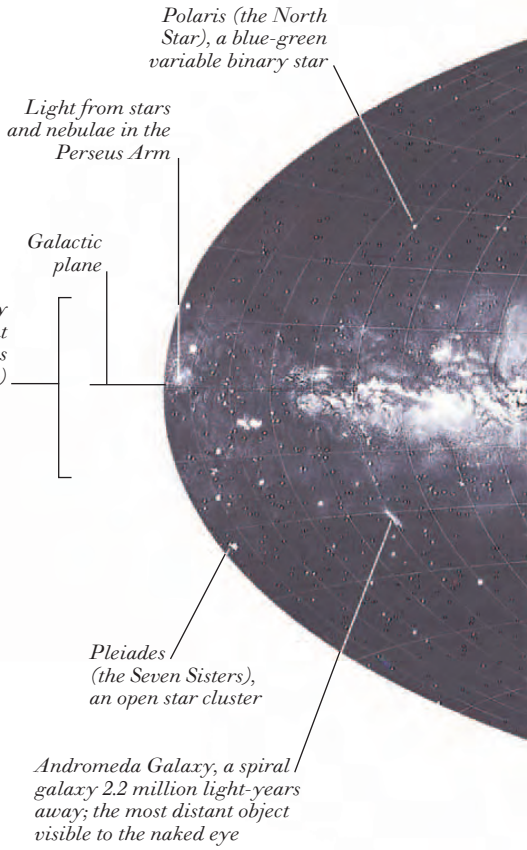
SIDE VIEW OF OUR GALAXY



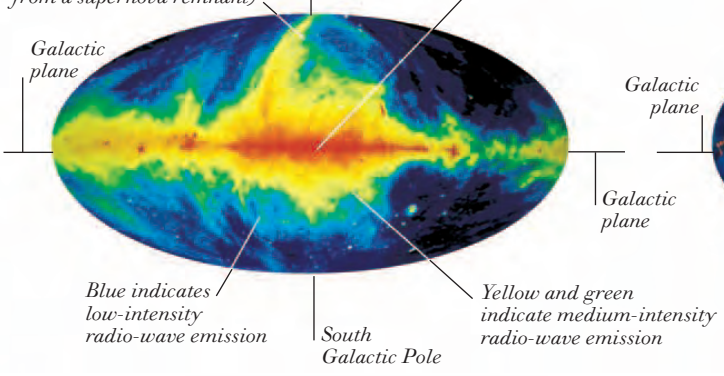
OVERHEAD VIEW OF OUR GALAXY



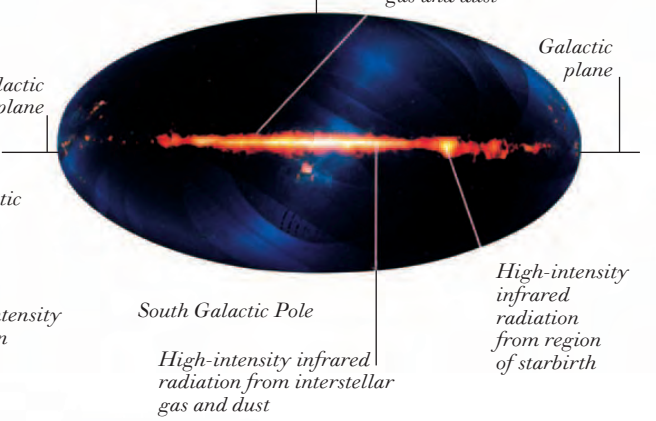
PANORAMIC OPTICAL MAP OF OUR GALAXY AND NEARBY GALAXIES

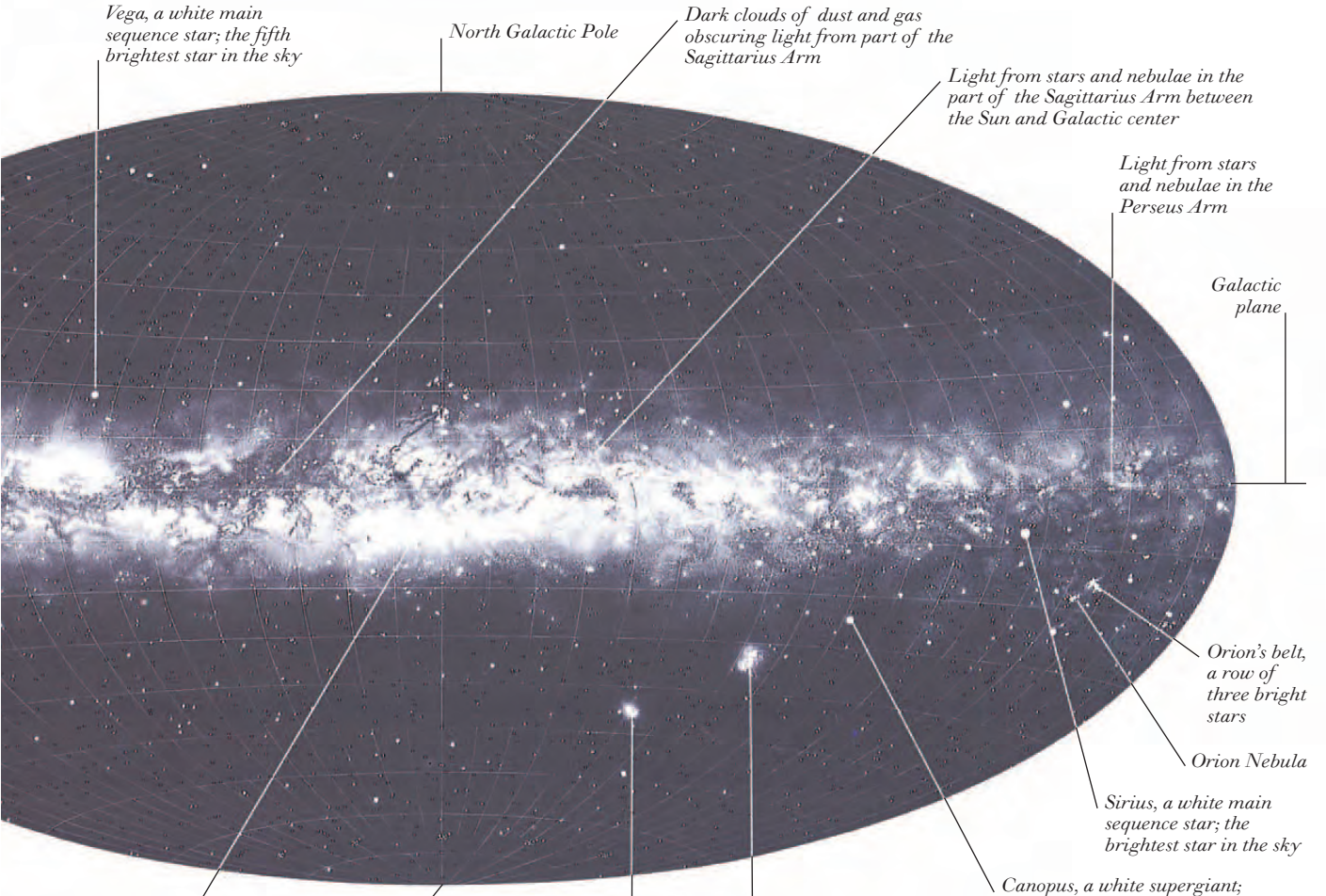


PANORAMIC RADIO MAP OF OUR GALAXY



PANORAMIC INFRARED MAP OF OUR GALAXY





Nebulae and star clusters

HODGE 11, A GLOBULAR CLUSTER

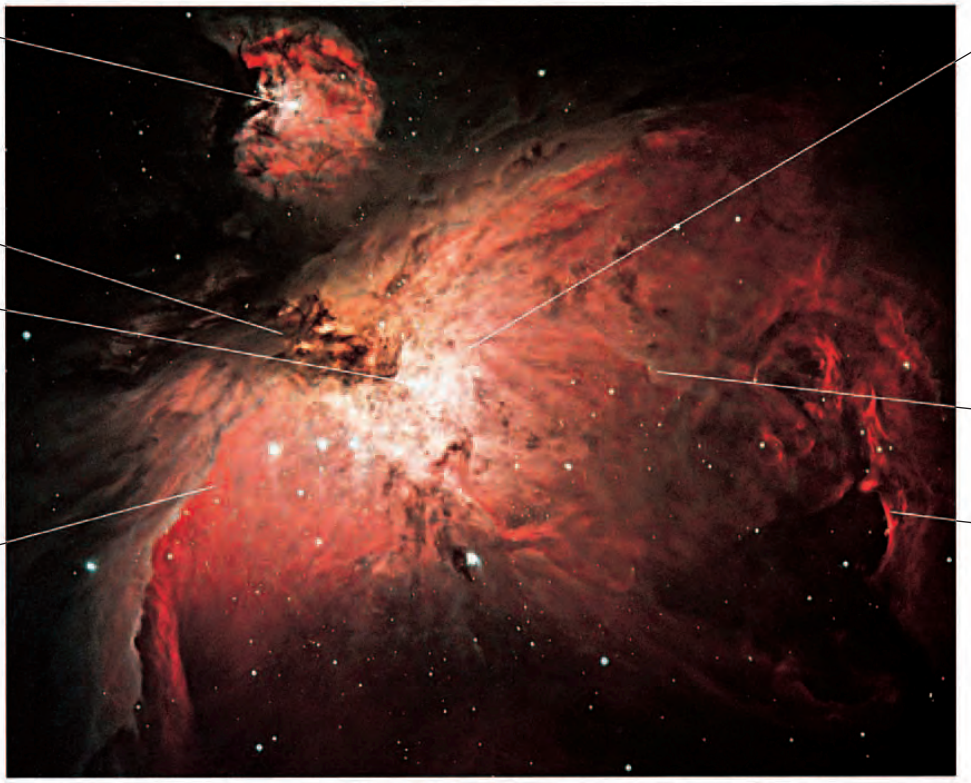
A NEBULA IS A CLOUD OF DUST AND GAS inside a galaxy. Nebulae become visible if the gas glows, or if the cloud reflects starlight or obscures light from more distant objects. Emission nebulae shine because their gas emits light when it is stimulated by radiation from hot young stars. Reflection nebulae shine because their dust reflects light from stars in or around the nebula. Dark nebulae appear as silhouettes because they block out light from shining nebulae or stars behind them. Two types of nebula are associated with dying stars: planetary nebulae and supernova remnants. Both consist of expanding shells of gas that were once the outer layers of a star. A planetary nebula is a gas shell drifting away from a dying stellar core. A supernova remnant is a gas shell moving away from a stellar core at great speed following a violent explosion called a supernova (see pp. 26-27). Stars are often found in groups known as clusters. Open clusters are loose groups of a few thousand young stars that were born from the same cloud and are drifting apart. Globular clusters are densely packed, roughly spherical groups of hundreds of thousands of older stars.

TRIFID NEBULA (EMISSION NEBULA)

PLEIADES (OPEN STAR CLUSTER) WITH A REFLECTION NEBULA

HORSEHEAD NEBULA (DARK NEBULA)

ORION NEBULA (DIFFUSE EMISSION NEBULA)

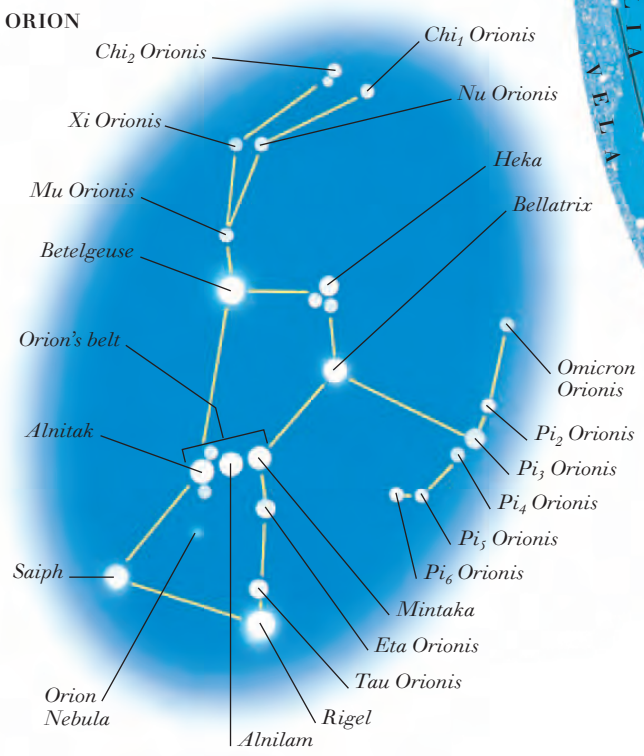


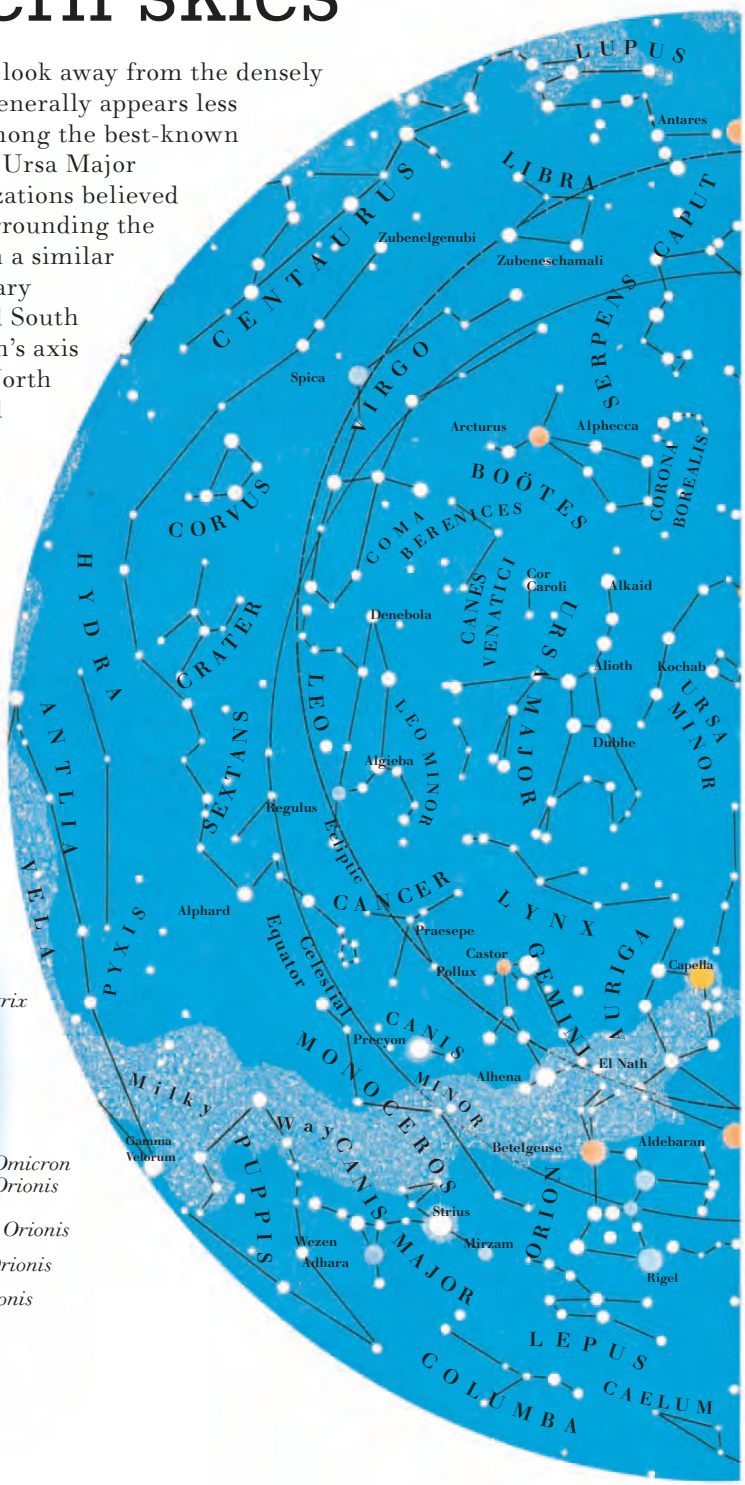
VELA SUPERNOVA REMNANT

HELIX NEBULA (PLANETARY NEBULA)

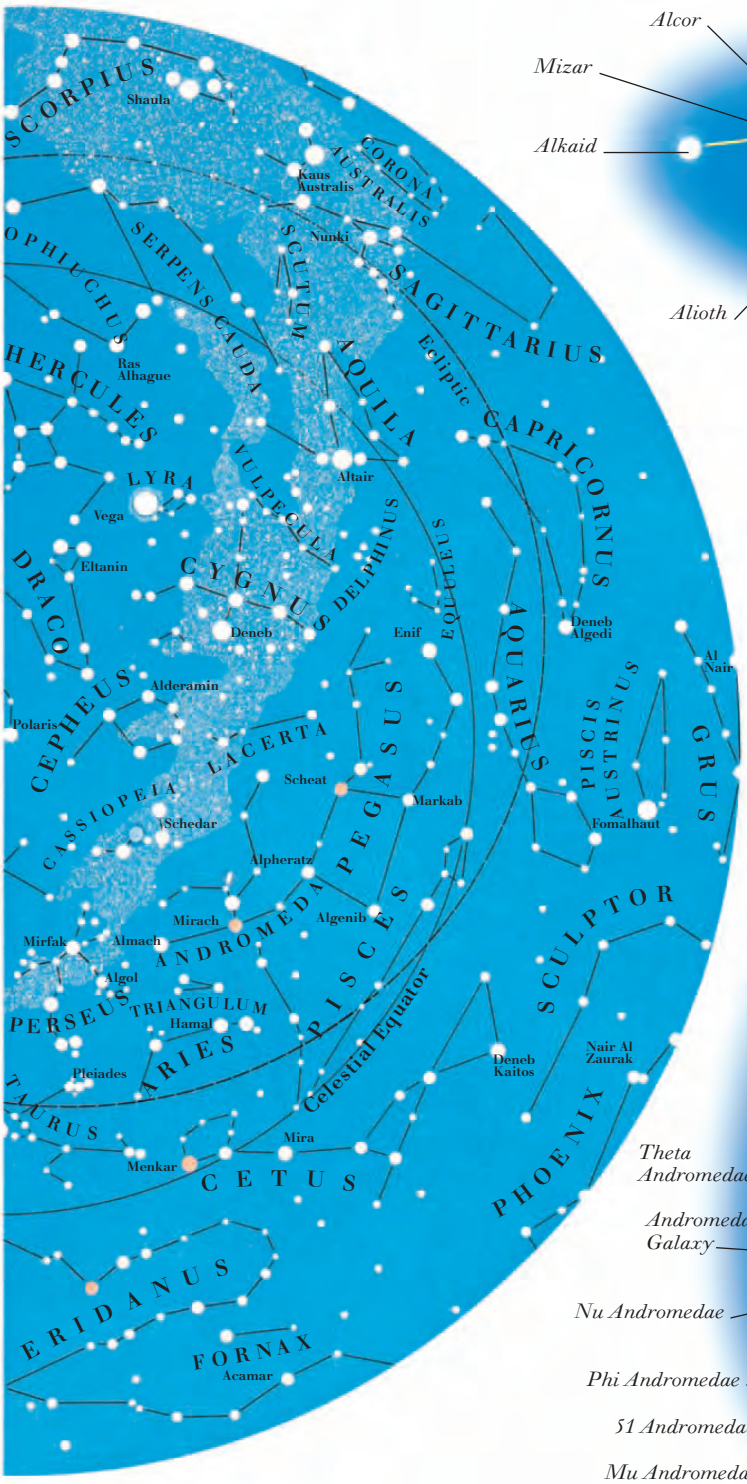
Stars of northern skies

WHEN YOU LOOK AT THE NORTHERN SKY, you look away from the densely populated Galactic center, so the northern sky generally appears less bright than the southern sky (see pp. 20-21). Among the best-known sights in the northern sky are the constellations Ursa Major (the Great Bear) and Orion. Some ancient civilizations believed that the stars were fixed to a celestial sphere surrounding the Earth, and modern maps of the sky are based on a similar idea. The North and South Poles of this imaginary celestial sphere are directly above the North and South Poles of the Earth, at the points where the Earth's axis of rotation intersects the sphere. The celestial North Pole is at the center of the map shown here, and Polaris (the North Star) lies very close to it. The celestial equator marks a projection of the Earth's equator on the sphere. The ecliptic marks the path of the Sun across the sky as the Earth orbits the Sun. The Moon and planets move against the background of the stars because the stars are much more distant; the nearest star outside the solar system (Proxima Centauri) is more than 50,000 times farther away than the planet Jupiter.

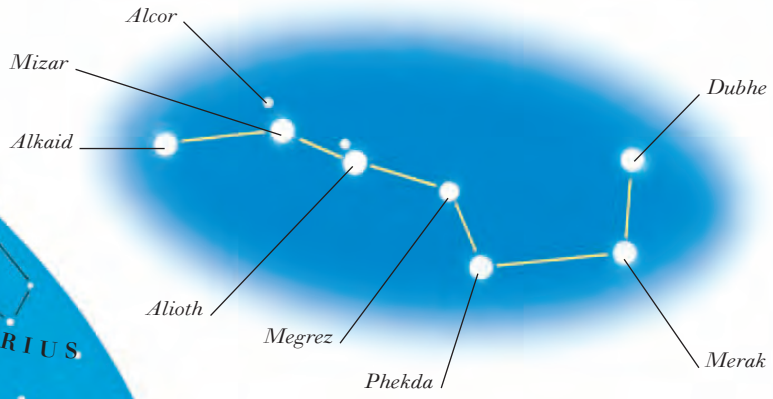




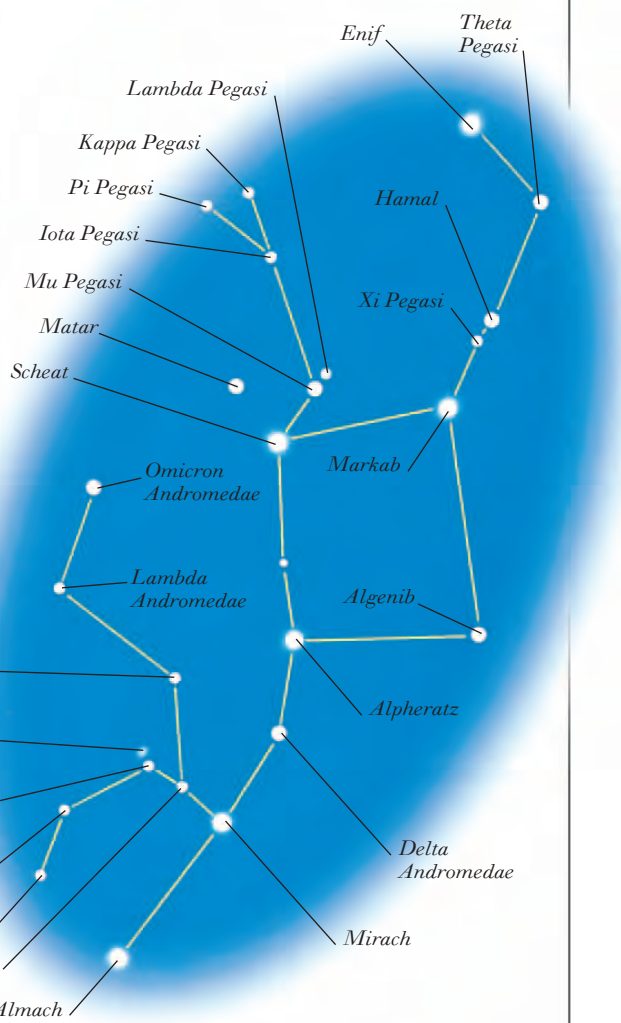
VISIBLE STARS IN THE NORTHERN SKY



THE BIG DIPPER, PART OF URSA MAJOR (THE GREAT BEAR)

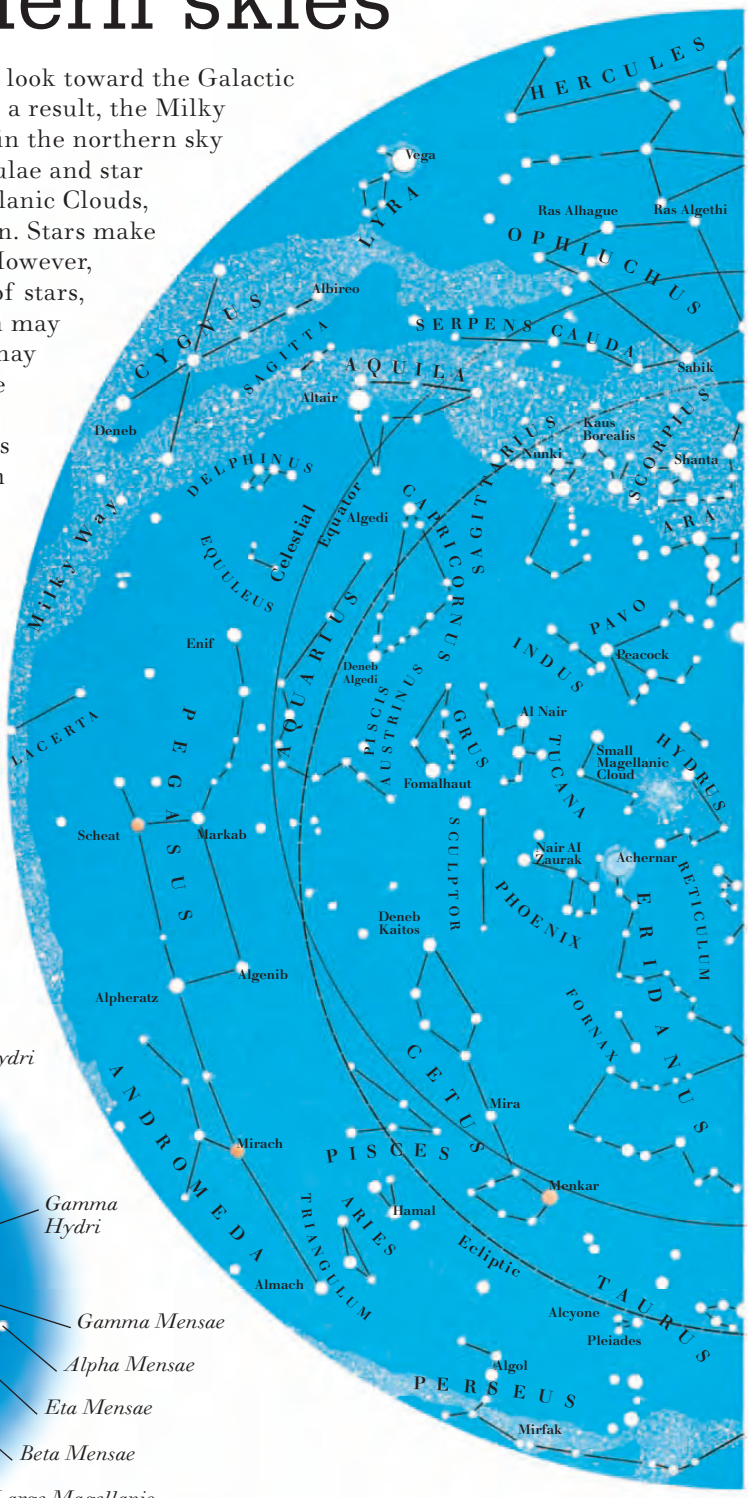


PEGASUS AND ANDROMEDA



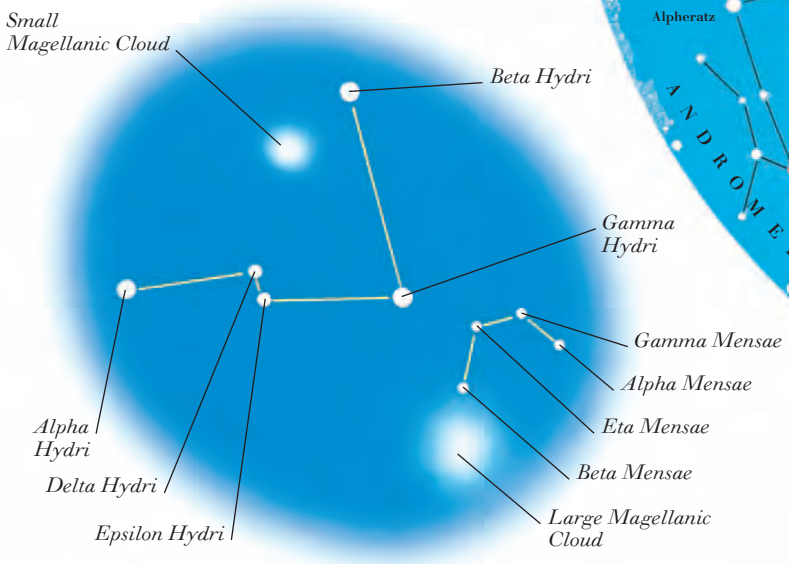
Stars of southern skies

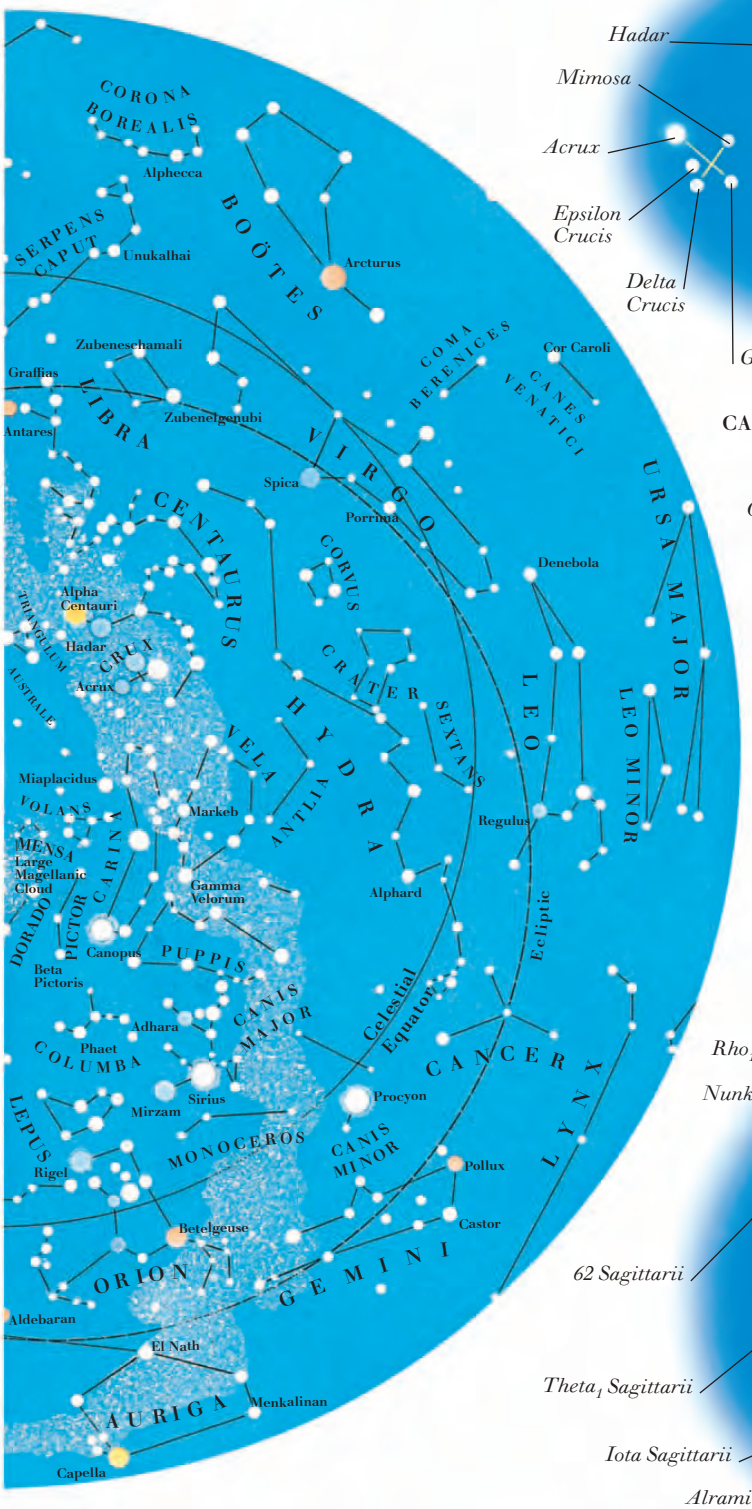
WHEN YOU LOOK AT THE SOUTHERN SKY, you look toward the Galactic center, which has a huge population of stars. As a result, the Milky Way appears brighter in the southern sky than in the northern sky (see pp. 18-19). The southern sky is rich in nebulae and star clusters. It contains the Large and Small Magellanic Clouds, which are two of the nearest galaxies to our own. Stars make fixed patterns in the sky called constellations. However, the constellations are only apparent groupings of stars, since the distances to the stars in a constellation may vary enormously. The shapes of constellations may change over many thousands of years due to the relative motions of stars. The movement of the constellations across the sky is due to the Earth's motion in space. The daily rotation of the Earth causes the constellations to move across the sky from east to west, and the orbit of the Earth around the Sun causes different areas of sky to be visible in different seasons. The visibility of areas of sky also depends on the location of the observer. For instance, stars near the celestial equator may be seen from either hemisphere at some time during the year, whereas stars close to the celestial poles (the celestial South Pole is at the center of the map shown here) can never be seen from the opposite hemisphere.



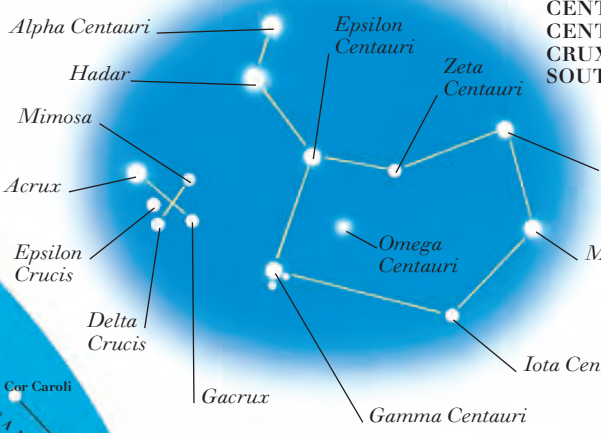
VISIBLE STARS IN THE SOUTHERN SKY

HYDRUS (THE WATER SNAKE) AND MENSA (THE TABLE)

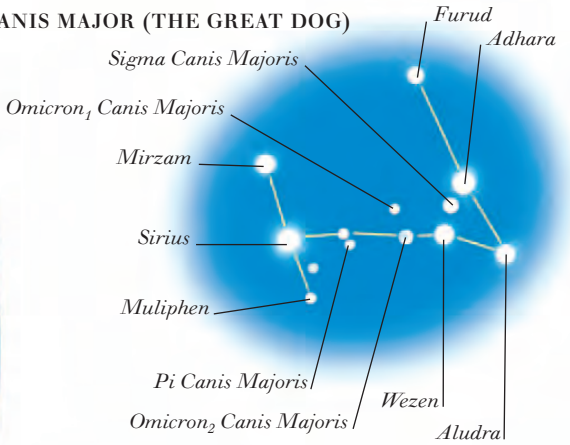




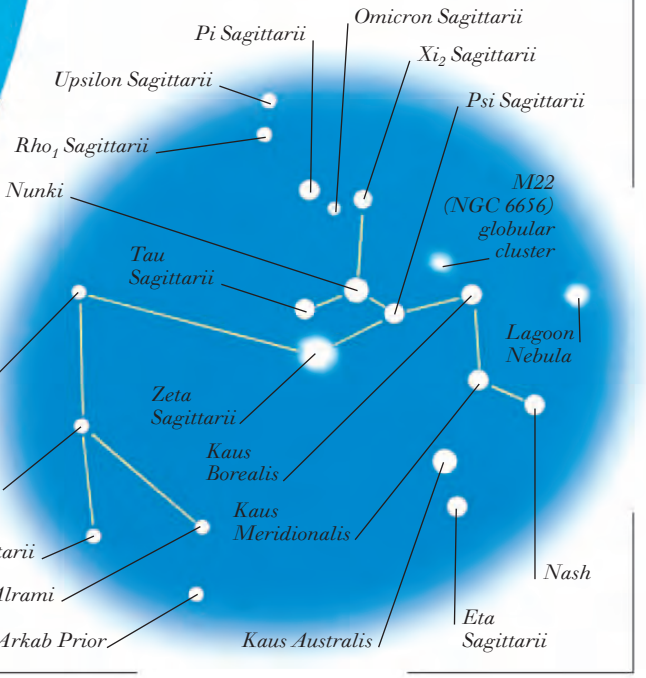
CENTAURUS (THE CENTAUR) AND CRUX (THE SOUTHERN CROSS)



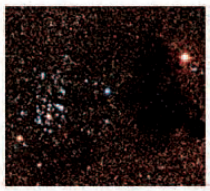
CANIS MAJOR (THE GREAT DOG)



SAGITTARIUS (THE ARCHER)



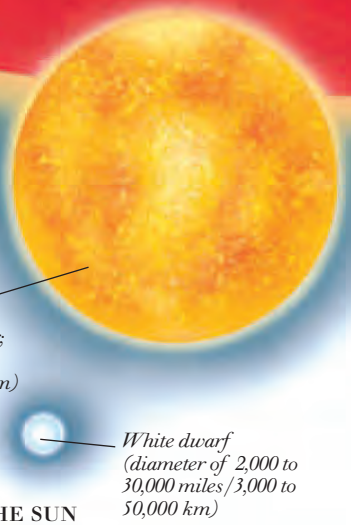
Stars



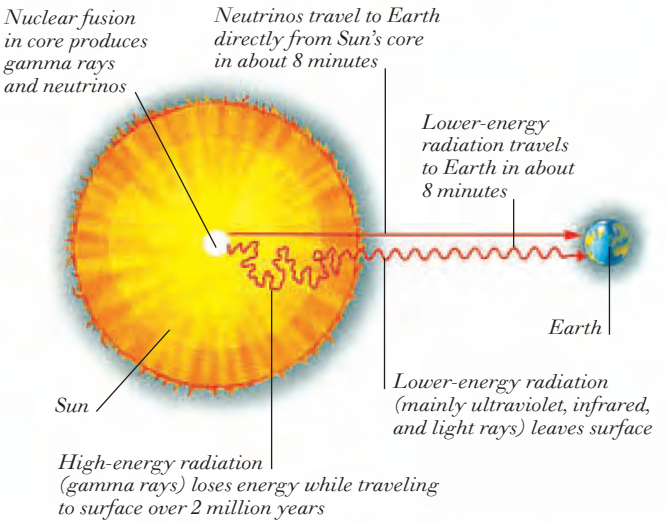
OPEN STAR CLUSTER AND DUST CLOUD

STARS ARE BODIES of hot, glowing gas that are born in nebulae (see pp. 24-27). They vary enormously in size, mass, and temperature: diameters range from about 450 times smaller to over 1,000 times bigger than that of the Sun; masses range from about a twentieth to over 50 solar masses; and surface temperatures range from about 5,500°F (3,000°C) to over 90,000°F (50,000°C). The color of a star is determined by its temperature: the hottest stars are blue and the coolest are red. The Sun, with a surface temperature of 10,000°F (5,500°C), is between these extremes and appears yellow. The energy emitted by a shining star is usually produced by nuclear fusion in the star's core. The brightness of a star is measured in magnitudes—the brighter the star, the lower its magnitude. There are two types of magnitude: apparent magnitude, which is the brightness seen from Earth, and absolute magnitude, which is the brightness that would be seen from a standard distance of 10 parsecs (32.6 light-years). The light emitted by a star may be split to form a spectrum containing a series of dark lines (absorption lines). The patterns of lines indicate the presence of particular chemical elements, enabling astronomers to deduce the composition of the star's atmosphere. The magnitude and spectral type (color) of stars may be plotted on a graph called a Hertzsprung-Russell diagram, which shows that stars tend to fall into several well-defined groups. The principal groups are main sequence stars (those which are fusing hydrogen to form helium), giants, supergiants, and white dwarfs.

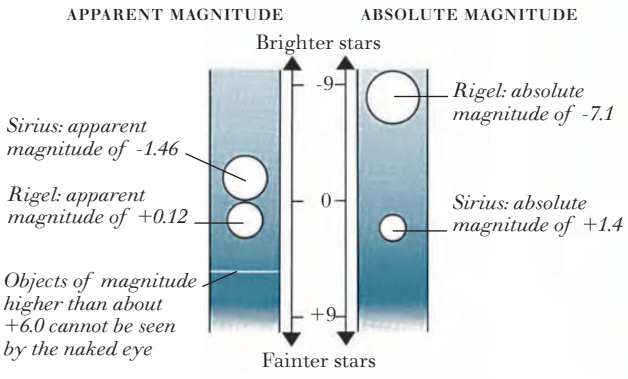
STAR SIZES



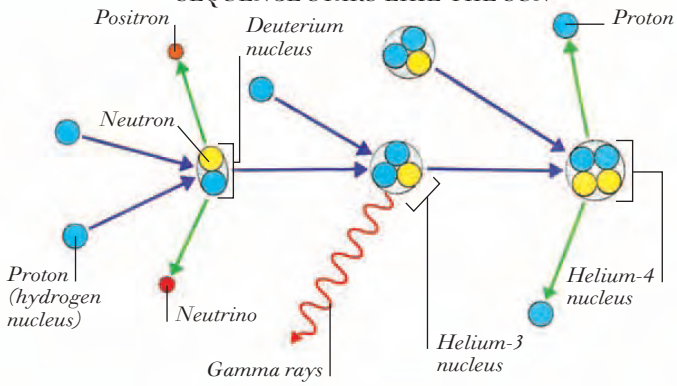
ENERGY EMISSION FROM THE SUN



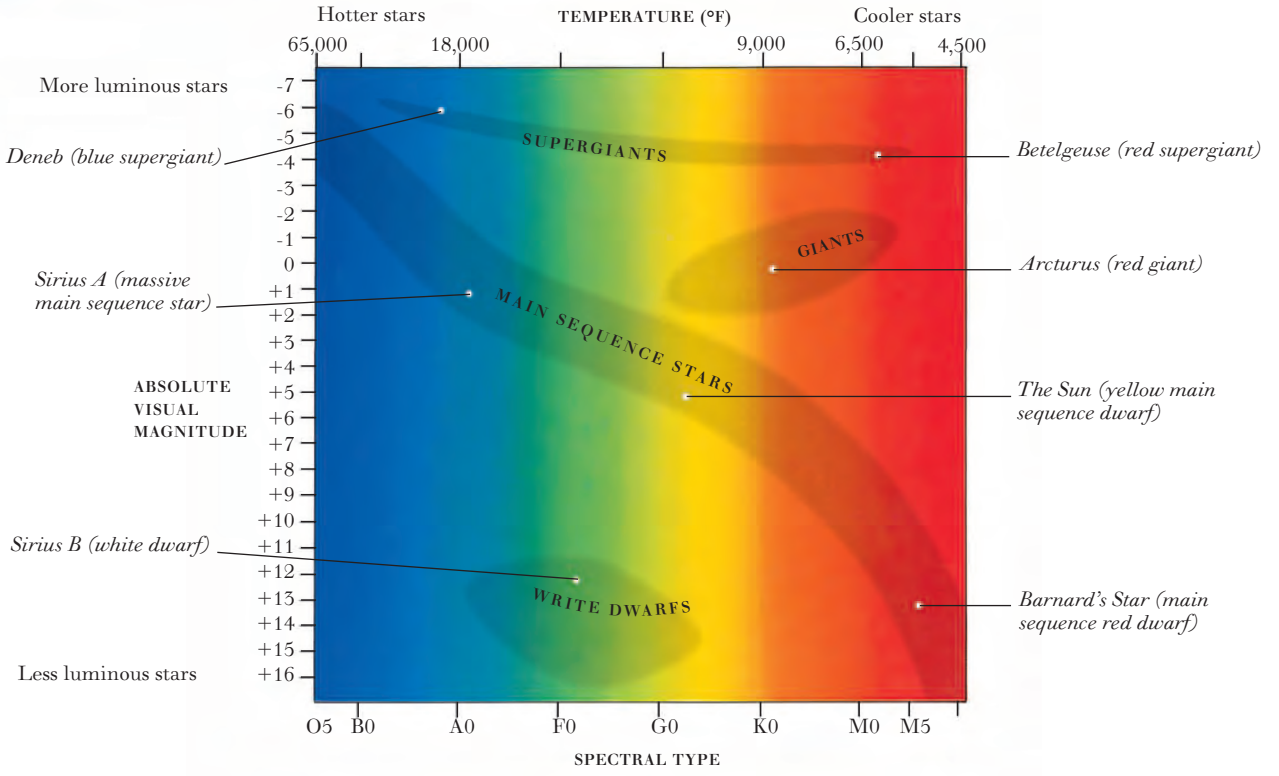
STAR MAGNITUDES



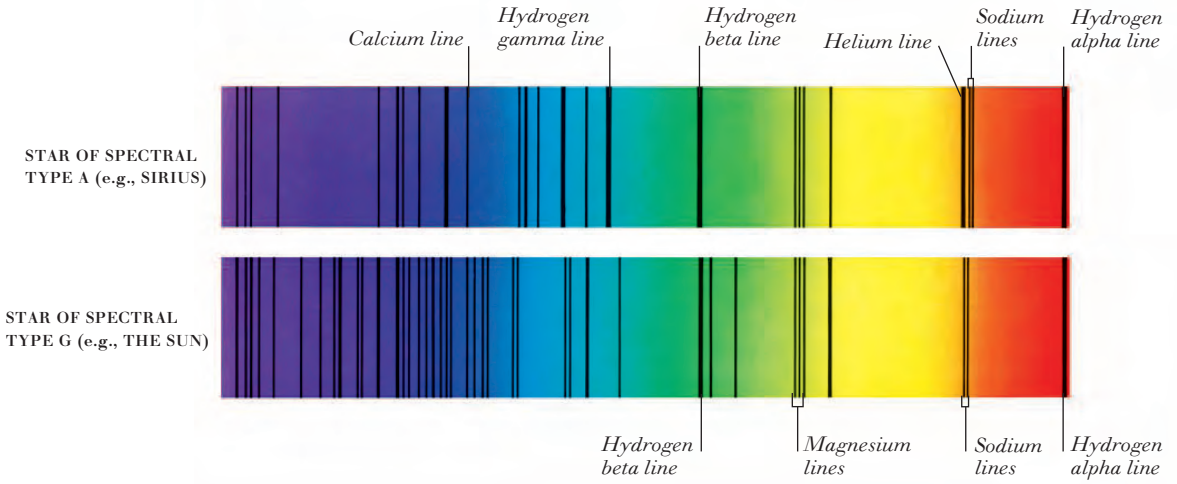
NUCLEAR FUSION IN MAIN SEQUENCE STARS LIKE THE SUN



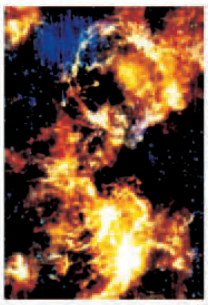
HERTZSPRUNG-RUSSELL DIAGRAM



STELLAR SPECTRAL ABSORPTION LINES



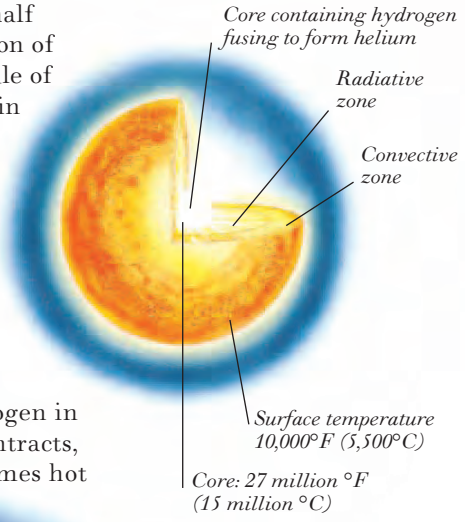
Small stars



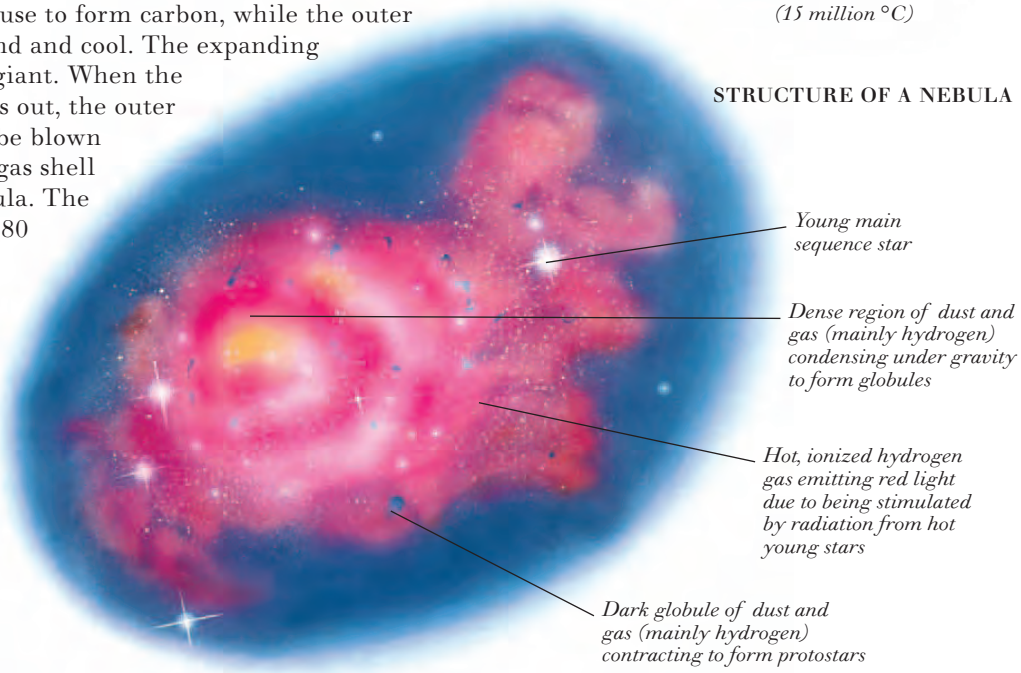
REGION OF STAR FORMATION IN ORION

SMALL STARS HAVE A MASS of up to about one and a half times that of the Sun. They begin to form when a region of higher density in a nebula condenses into a huge globule of gas and dust that contracts under its own gravity. Within a globule, regions of condensing matter heat up and begin to glow, forming protostars. If a protostar contains enough matter, the central temperature reaches about 27 million °F (8 million °C). At this temperature, nuclear reactions in which hydrogen fuses to form helium can start. This process releases energy, which prevents the star from contracting more and also causes it to shine; it is now a main sequence star. A star of about one solar mass remains on the main sequence for about 10 billion years, until much of the hydrogen in the star's core has been converted into helium. The helium core then contracts, and nuclear reactions continue in a shell around the core. The core becomes hot enough for helium to fuse to form carbon, while the outer layers of the star expand and cool. The expanding star is known as a red giant. When the helium in the core runs out, the outer layers of the star may be blown away as an expanding gas shell called a planetary nebula. The remaining core (about 80 percent of the original star) is now in its final stages. It becomes a white dwarf star that gradually cools and dims. When it finally stops shining altogether, the dead star will become a black dwarf.

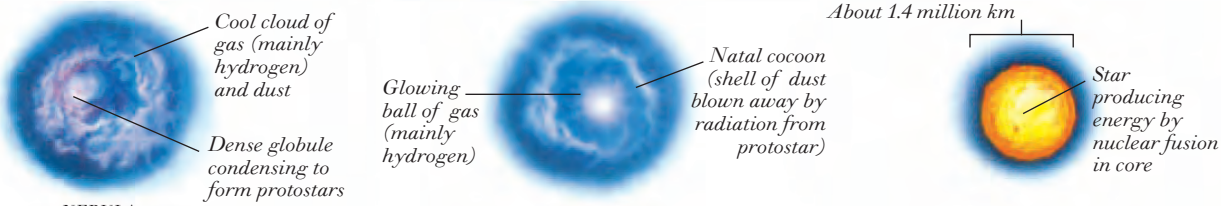
STRUCTURE OF A MAIN SEQUENCE STAR



STRUCTURE OF A NEBULA



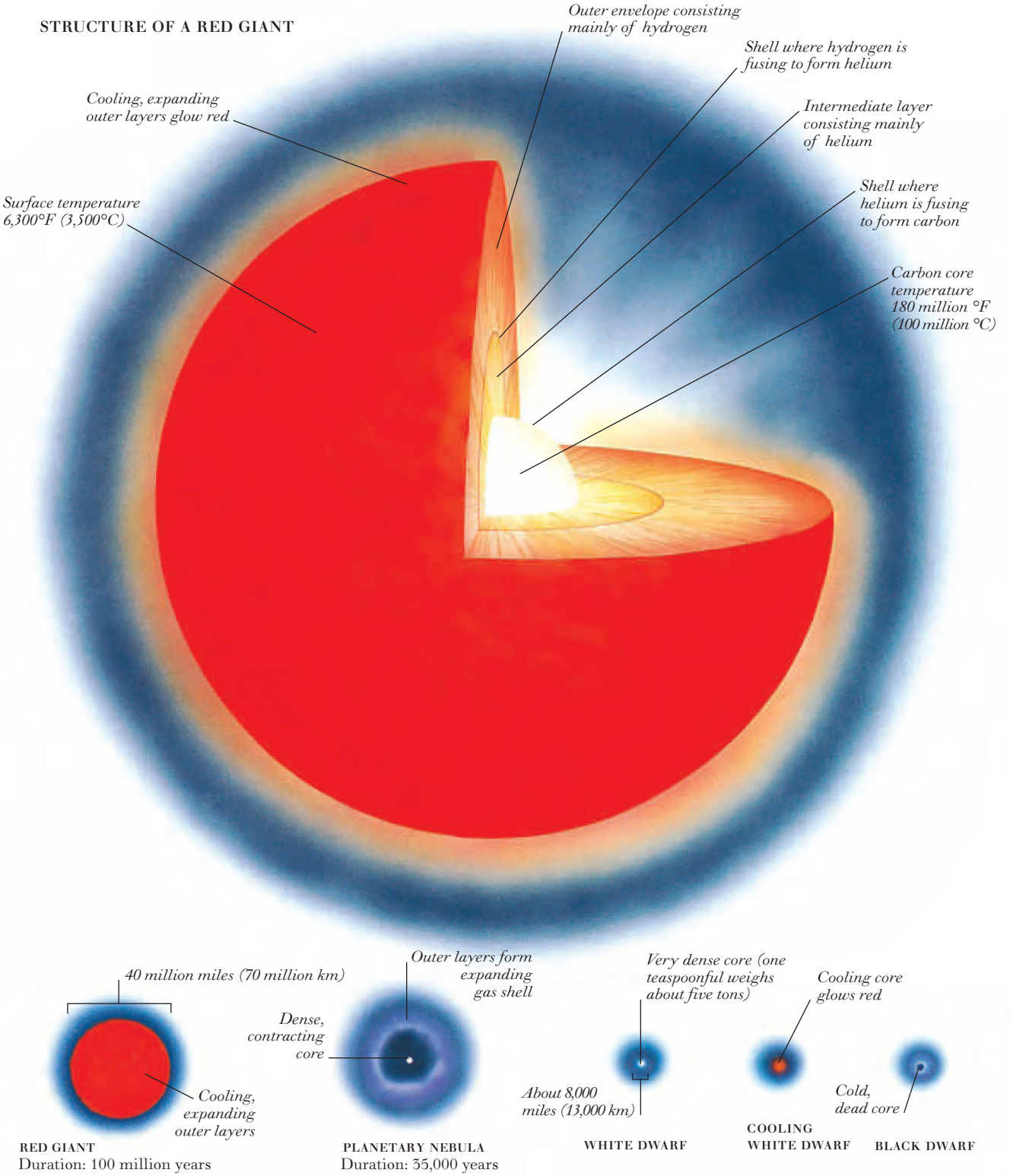
LIFE OF A SMALL STAR OF ABOUT ONE SOLAR MASS



NEBULA

PROTOSTAR
Duration: 50 million years

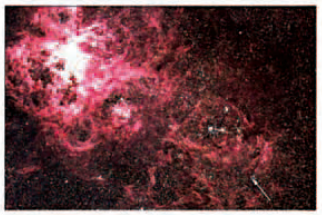
MAIN SEQUENCE STAR
Duration: 10 billion years


STRUCTURE OF A RED GIANT
Outer envelope consisting mainly of hydrogen
Shell where hydrogen is fusing to form helium
Cooling, expanding outer layers glow red
Intermediate layer consisting mainly of helium
Surface temperature 6,300°F (3,500°C)
Shell where helium is fusing to form carbon
Carbon core temperature 180 million °F (100 million °C)
40 million miles (70 million km)
Cooling, expanding outer layers
RED GIANT
Duration: 100 million years
Outer layers form expanding gas shell
Dense, contracting core
PLANETARY NEBULA
Duration: 35,000 years
Very dense core (one teaspoonful weighs about five tons)
About 8,000 miles (13,000 km)
WHITE DWARF
Cooling core glows red
COOLING WHITE DWARF
Cold, dead core
BLACK DWARF

Massive stars

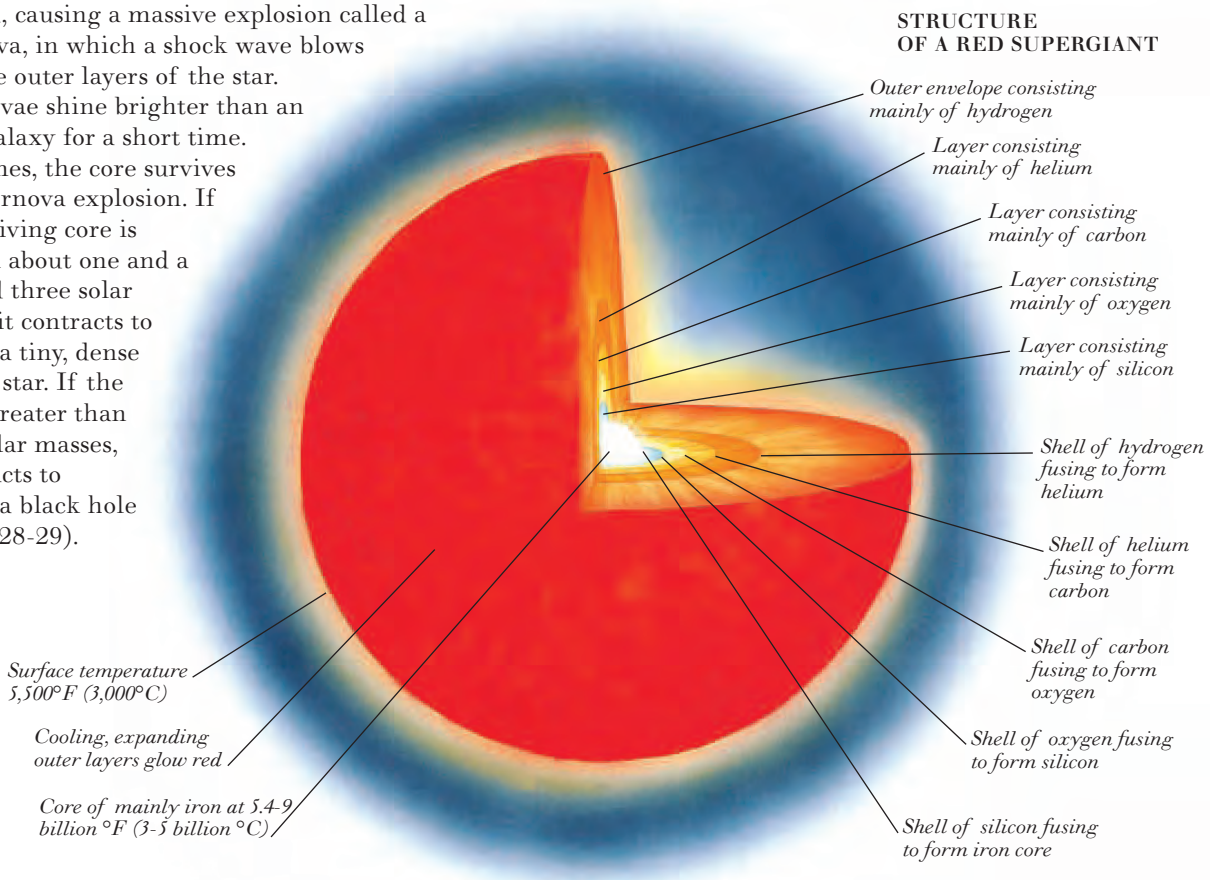
MASSIVE STARS HAVE A MASS AT LEAST THREE TIMES that of the Sun, and some stars are as massive as about 50 Suns. A massive star evolves in a similar way to a small star until it reaches the main sequence stage (see pp. 24-25). During its life as a main sequence star, it shines steadily until the hydrogen in its core has fused to form helium. This process takes billions of years in a small star, but only millions of years in a massive star. A massive star then becomes a red supergiant, which initially consists of a helium core surrounded by outer layers of cooling, expanding gas. Over the next few million years, a series of nuclear reactions form different elements in shells around an iron core. The core eventually collapses in less than a second, causing a massive explosion called a supernova, in which a shock wave blows away the outer layers of the star. Supernovae shine brighter than an entire galaxy for a short time. Sometimes, the core survives the supernova explosion. If the surviving core is between about one and a half and three solar masses, it contracts to become a tiny, dense neutron star. If the core is greater than three solar masses, it contracts to become a black hole (see pp. 28-29).

SUPERNOVA

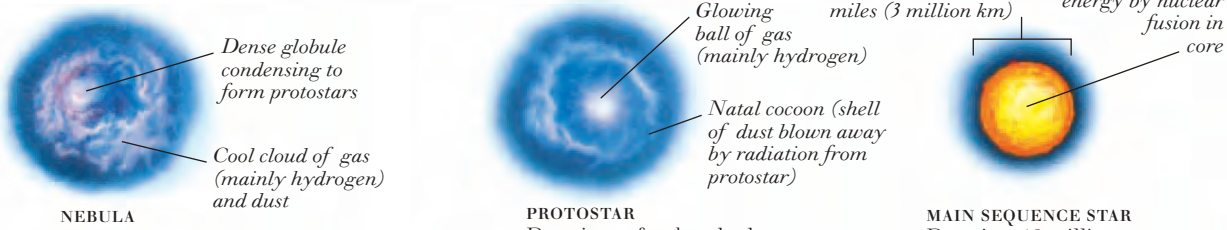


TARANTULA NEBULA BEFORE SUPERNOVA

STRUCTURE OF A RED SUPERGIANT



LIFE OF A MASSIVE STAR OF ABOUT 10 SOLAR MASSES

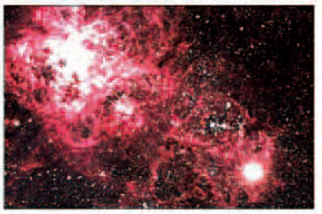


NEBULA

PROTOSTAR
Duration: a few hundred thousand years

MAIN SEQUENCE STAR
Duration: 10 million years

FEATURES OF A SUPERNOVA



TARANTULA NEBULA SHOWING SUPERNOVA IN 1987

Ejecta (outer layers of star thrown off during explosion) travels at 6,000 miles/sec (10,000 km/sec)

Shock wave travels outward from core at 20,000 miles/sec (30,000 km/sec)

Reverse shock wave moves inward and heats ejecta, causing it to shine

Chemical elements heavier than iron are produced in the explosion and scattered into space

Central temperature: 18 billion °F (10 billion °C)

Contracting core consisting mainly of neutrons remains after explosion

Light energy of a billion Suns emitted during explosion

Extremely dense core (one teaspoonful weighs about a billion tons)

6 miles (4 km)

Core mass of less than three solar masses

NEUTRON STAR

60 million miles (100 million km)

Cooling, expanding outer layers

RED SUPERGIANT
Duration: 4 million years

Outer layers of star blown off in explosion

Contracting stellar core may remain after supernova

SUPERNOVA
Duration of visibility: 1–2 years

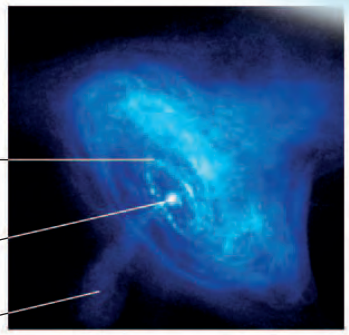
Core of mass greater than three solar masses continues contracting to become black hole

Accretion disk

BLACK HOLE

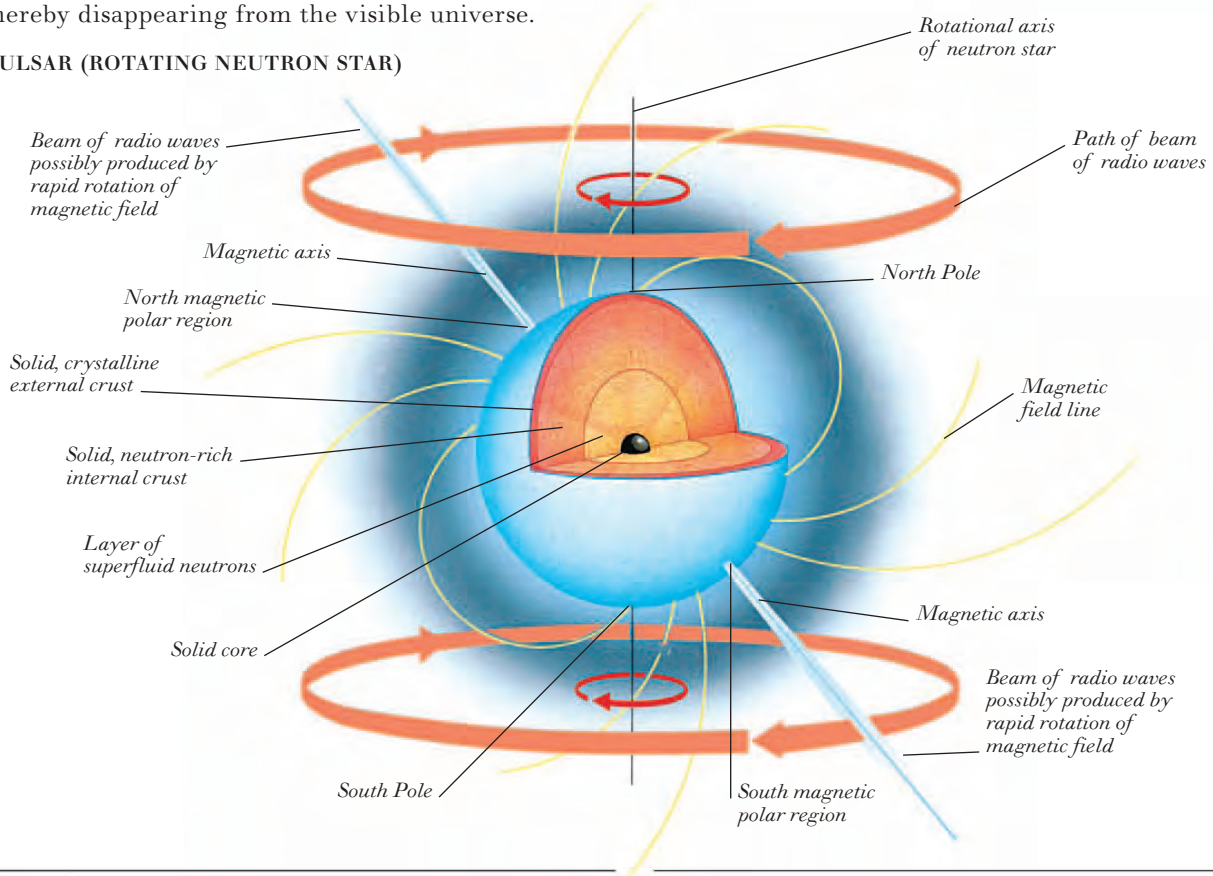
Neutron stars and black holes

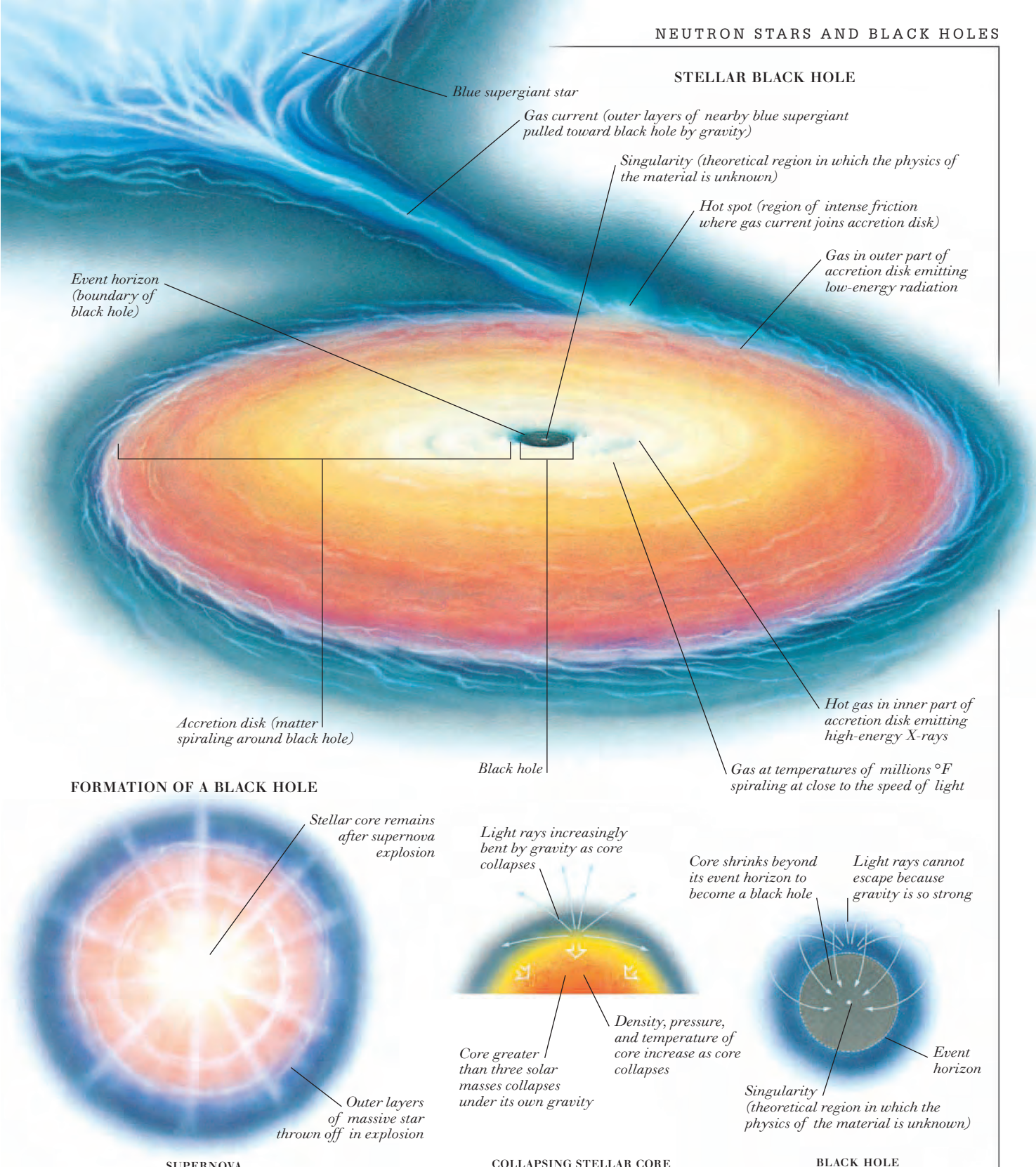
NEUTRON STARS AND BLACK HOLES form from the stellar cores that remain after stars have exploded as supernovae (see pp. 26-27). If the remaining core is between about one and a half and three solar masses, it contracts to form a neutron star. If the remaining core is greater than about three solar masses, it contracts to form a black hole. Neutron stars are typically only about 6 miles (10 km) in diameter and consist almost entirely of subatomic particles called neutrons. Such stars are so dense that a teaspoonful would weigh about a billion tons. Neutron stars are observed as pulsars, so-called because they rotate rapidly and emit two beams of radio waves, which sweep across the sky and are detected as short pulses. Black holes are characterized by their extremely strong gravity, which is so powerful that not even light can escape; as a result, black holes are invisible. However, they can be detected if they have a close companion star. The gravity of the black hole pulls gas from the other star, forming an accretion disk that spirals around the black hole at high speed, heating up and emitting radiation. Eventually, the matter spirals in to cross the event horizon (the boundary of the black hole), thereby disappearing from the visible universe.



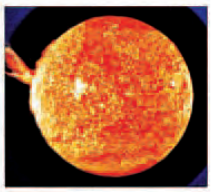
X-RAY IMAGE OF PULSAR AND CENTRAL REGION OF CRAB NEBULA (SUPERNOVA REMNANT)

PULSAR (ROTATING NEUTRON STAR)



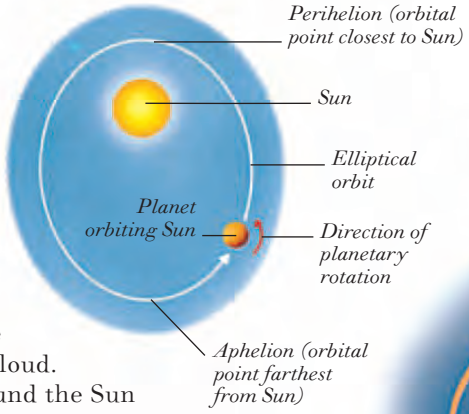

STELLAR BLACK HOLE
Blue supergiant star
Gas current (outer layers of nearby blue supergiant pulled toward black hole by gravity)
Singularity (theoretical region in which the physics of the material is unknown)
Hot spot (region of intense friction where gas current joins accretion disk)
Gas in outer part of accretion disk emitting low-energy radiation
Event horizon (boundary of black hole)
Accretion disk (matter spiraling around black hole)
Black hole
Hot gas in inner part of accretion disk emitting high-energy X-rays
Gas at temperatures of millions °F spiraling at close to the speed of light
FORMATION OF A BLACK HOLE
Stellar core remains after supernova explosion
Outer layers of massive star thrown off in explosion
SUPERNOVA
Light rays increasingly bent by gravity as core collapses
Core greater than three solar masses collapses under its own gravity
Density, pressure, and temperature of core increase as core collapses
COLLAPSING STELLAR CORE
Core shrinks beyond its event horizon to become a black hole
Light rays cannot escape because gravity is so strong
Event horizon
Singularity (theoretical region in which the physics of the material is unknown)
BLACK HOLE

The solar system

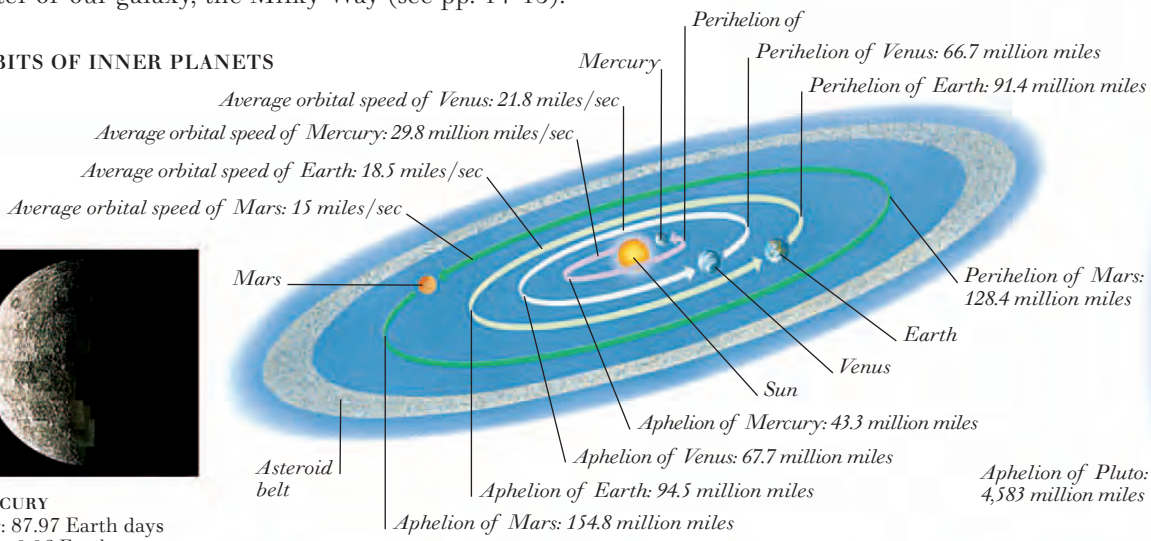


THE SOLAR SYSTEM consists of a central star (the Sun) and the bodies that orbit it. These bodies include eight planets and their more than 160 known moons; dwarf planets; Kuiper Belt objects; asteroids; comets; and meteoroids. The solar system also contains interplanetary gas and dust. The planets fall into two groups: four small rocky planets near the Sun (Mercury, Venus, Earth, and Mars); and four planets farther out, the giants (Jupiter, Saturn, Uranus, and Neptune). Between the rocky planets and giants is the asteroid belt, which contains thousands of chunks of rock orbiting the Sun. Beyond Neptune is the Kuiper Belt and, more distant, the Oort Cloud. Most of the bodies in the planetary part of the solar system move around the Sun in elliptical orbits located in a thin disk around the Sun's equator. All the planets orbit the Sun in the same direction (counterclockwise when viewed from above) and all but Venus and Uranus also spin about their axes in this direction. Moons also spin as they, in turn, orbit their planets. The entire solar system orbits the center of our galaxy, the Milky Way (see pp. 14-15).

PLANETARY ORBIT (EXAGGERATED)



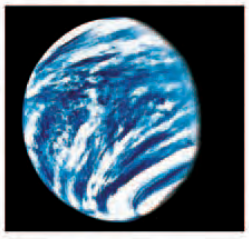
ORBITS OF INNER PLANETS



Aphelion of Neptune: 2.8 billion miles

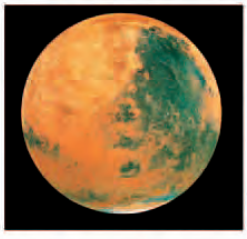
Aphelion of Pluto: 4,583 million miles

MERCURY
Year: 87.97 Earth days
Mass: 0.06 Earth masses
Diameter: 3,051 miles

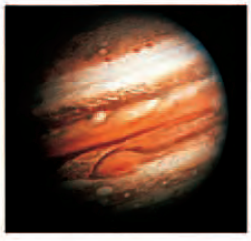


VENUS
Year: 224.7 Earth days
Mass: 0.81 Earth masses
Diameter: 7,521 miles

EARTH
Year: 365.26 days
Mass: 1 Earth mass
Diameter: 7,926 miles

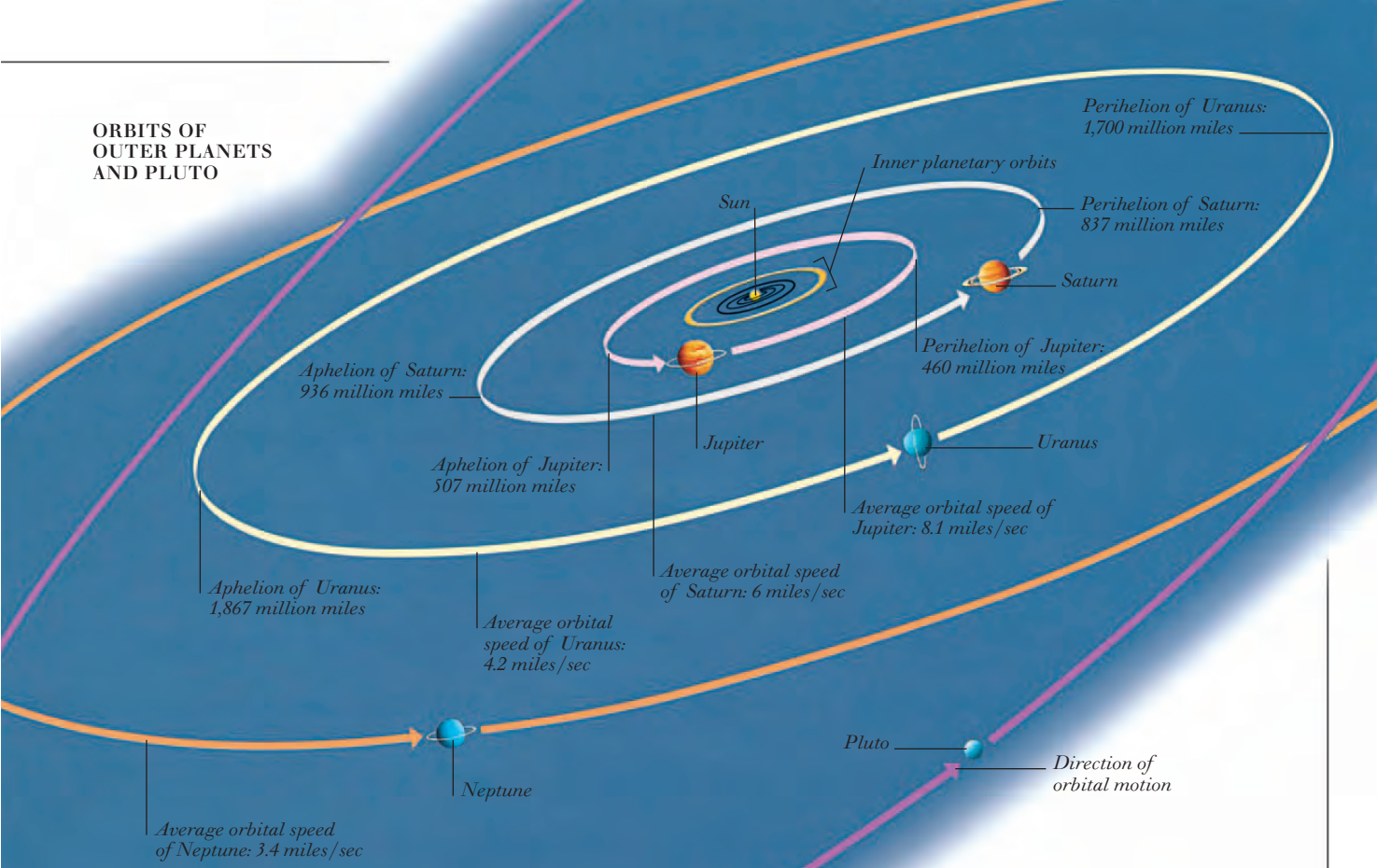


MARS
Year: 1.88 Earth years
Mass: 0.11 Earth masses
Diameter: 4,217 miles

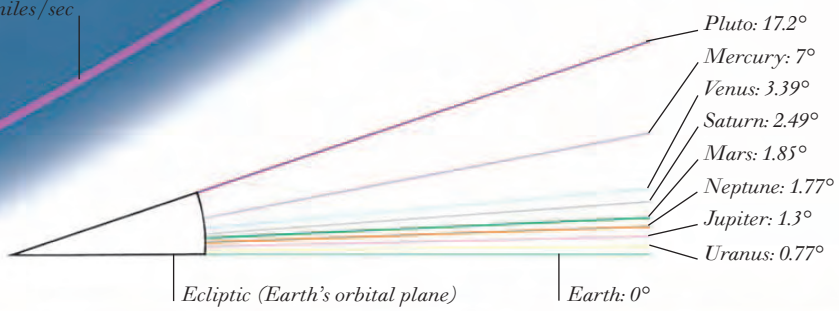


JUPITER
Year: 11.87 Earth years
Mass: 317.83 Earth masses
Diameter: 88,850 miles

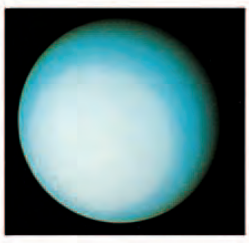
ORBITS OF OUTER PLANETS AND PLUTO



INCLINATION OF ORBITS TO THE ECLIPTIC

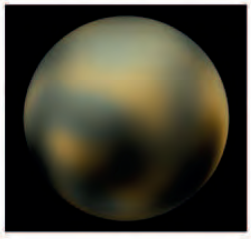


SATURN
Year: 29.66 Earth years
Mass: 95.16 Earth masses
Diameter: 74,901 miles



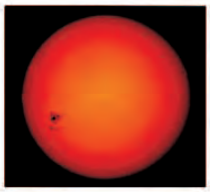
URANUS
Year: 84.13 Earth years
Mass: 14.54 Earth masses
Diameter: 31,765 miles

NEPTUNE
Year: 164.70 Earth years
Mass: 17.14 Earth masses
Diameter: 30,777 miles



PLUTO
Year: 248.09 Earth years
Mass: 0.0022 Earth masses
Diameter: 1,429 miles

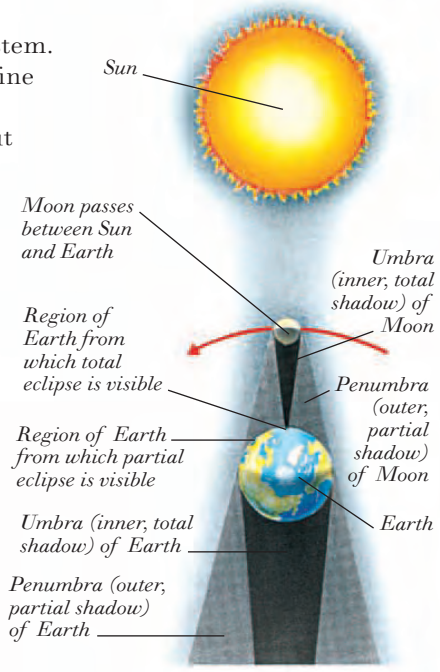
The Sun



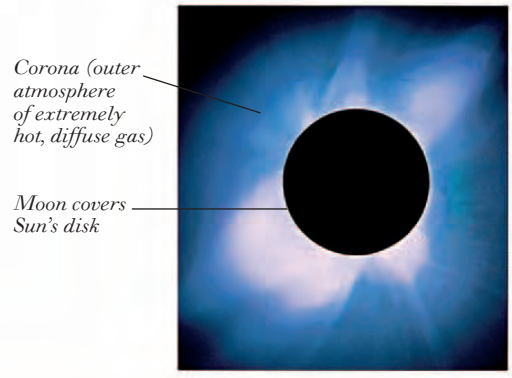
SOLAR PHOTOSPHERE

THE SUN IS THE STAR AT THE CENTER of the solar system. It is about five billion years old and will continue to shine as it does now for about another five billion years. The Sun is a yellow main sequence star (see pp. 22-23) about 870,000 miles (1.4 million km) in diameter. It consists almost entirely of hydrogen and helium. In the Sun's core, hydrogen is converted to helium by nuclear fusion, releasing energy in the process. The energy travels from the core, through the radiative and convective zones, to the photosphere (visible surface), where it leaves the Sun in the form of heat and light. On the photosphere there are often dark, relatively cool areas called sunspots, which usually appear in pairs or groups and are caused by the cooling effect of the magnetic field. Other types of solar activity are flares, which are usually associated with sunspots, and prominences. Flares are sudden discharges of high-energy radiation and atomic particles. Prominences are huge loops or filaments of gas extending into the solar atmosphere; some last for hours, others for months. Beyond the photosphere is the chromosphere (inner atmosphere) and the extremely rarified corona (outer atmosphere), which extends millions of miles into space. Tiny particles that escape from the corona give rise to the solar wind, which streams through space at hundreds of miles per second. The chromosphere and corona can be seen from Earth when the Sun is totally eclipsed by the Moon.

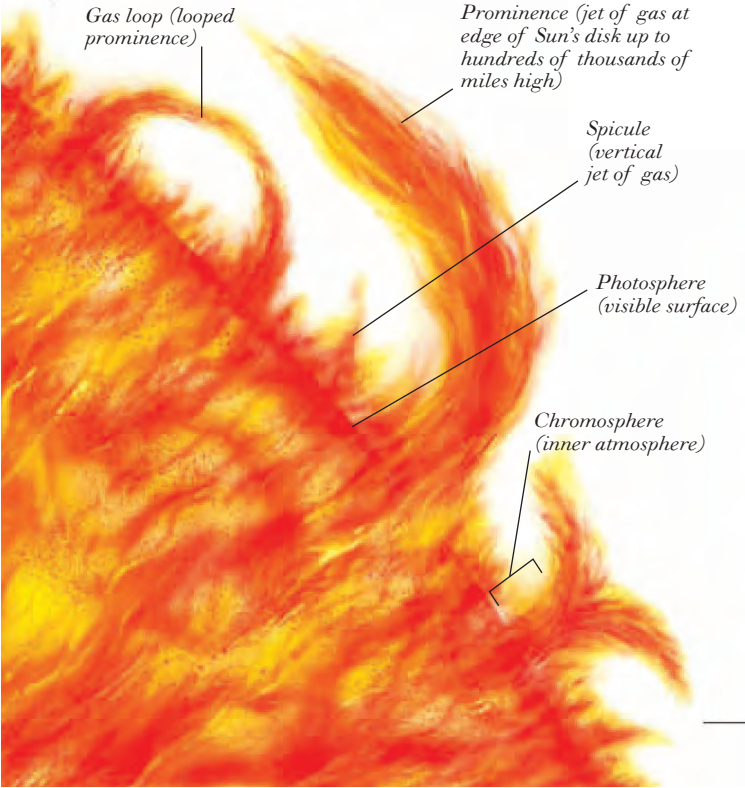
HOW A SOLAR ECLIPSE OCCURS



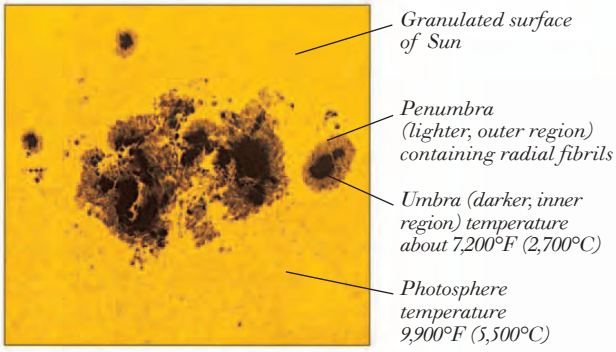
TOTAL SOLAR ECLIPSE



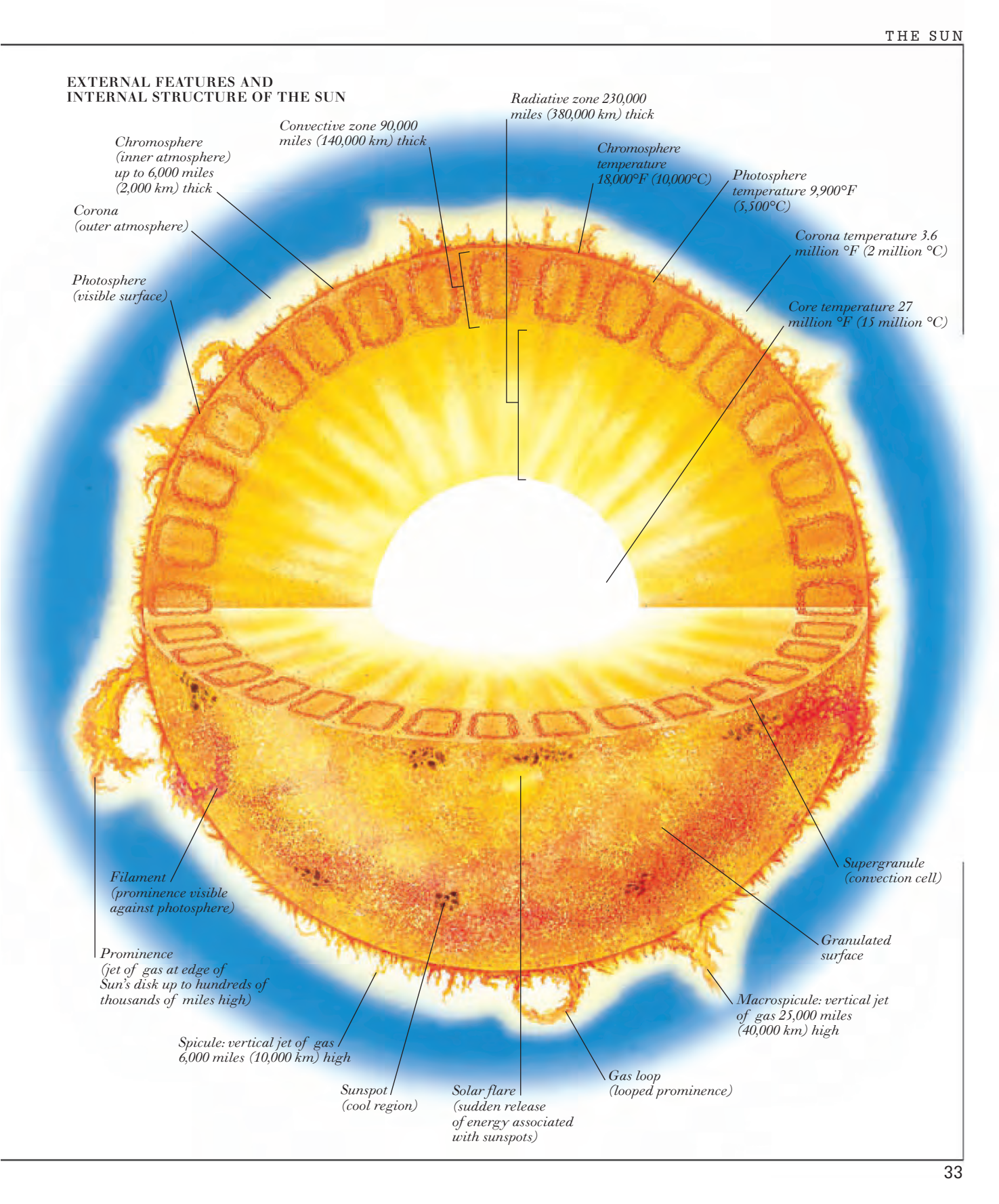
SURFACE FEATURES



SUNSPOTS



EXTERNAL FEATURES AND INTERNAL STRUCTURE OF THE SUN

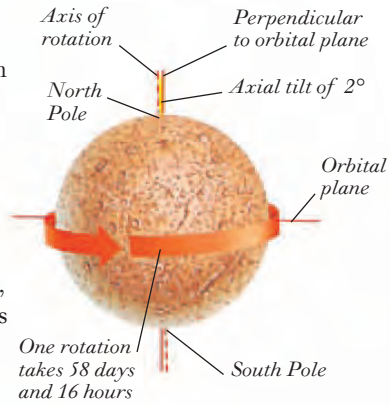


Mercury

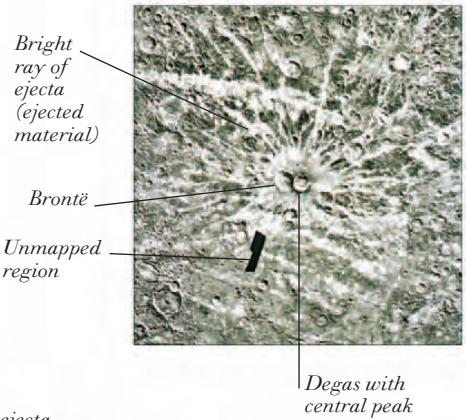
MERCURY

MERCURY IS THE NEAREST PLANET to the Sun, orbiting at an average distance of about 36 million miles (58 million km). Because Mercury is the closest planet to the Sun, it moves faster than any other planet, travelling at an average speed of nearly 30 miles (48 km) per second and completing an orbit in just under 88 days. Mercury is very small (only 40 percent bigger than the Moon) and rocky. Most of the surface has been heavily cratered by the impact of meteorites, although there are also smooth, sparsely cratered lava-covered plains. The Caloris Basin is the largest crater, measuring about 800 miles (1,300 km) across. It is thought to have been formed when a 38-mile- (60-km-) diameter asteroid hit the planet, and is surrounded by concentric rings of mountains thrown up by the impact. The surface also has many clifflike ridges (called rupes) that are thought to have been formed when the hot core of the young planet cooled and shrank about four billion years ago, buckling the planet's surface in the process. The planet rotates about its axis very slowly, taking nearly 59 Earth days to complete one rotation. As a result, a solar day (sunrise to sunrise) on Mercury is about 176 Earth days—twice as long as the 88-day Mercurian year. Mercury has extreme surface temperatures, ranging from a maximum of 800°F (430°C) on the sunlit side to -270°F (-170°C) on the dark side. At nightfall, the temperature drops very quickly because the planet's atmosphere is almost nonexistent. It consists only of minute amounts of helium and hydrogen captured from the solar wind, plus traces of other gases.

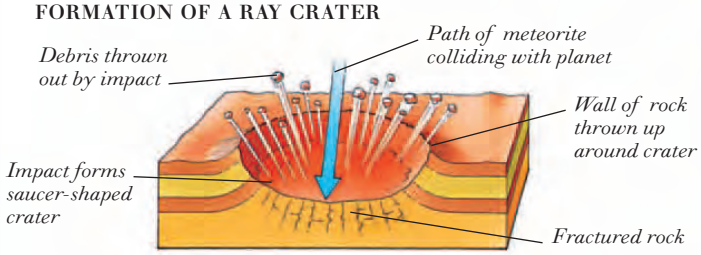
TILT AND ROTATION OF MERCURY



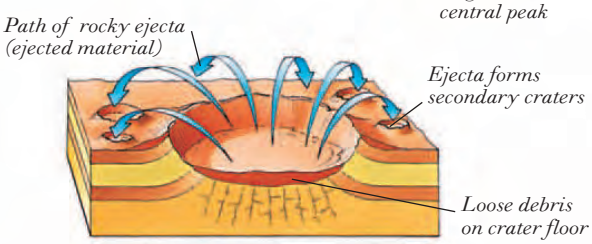
DEGAS AND BRONTË (RAY CRATERS)



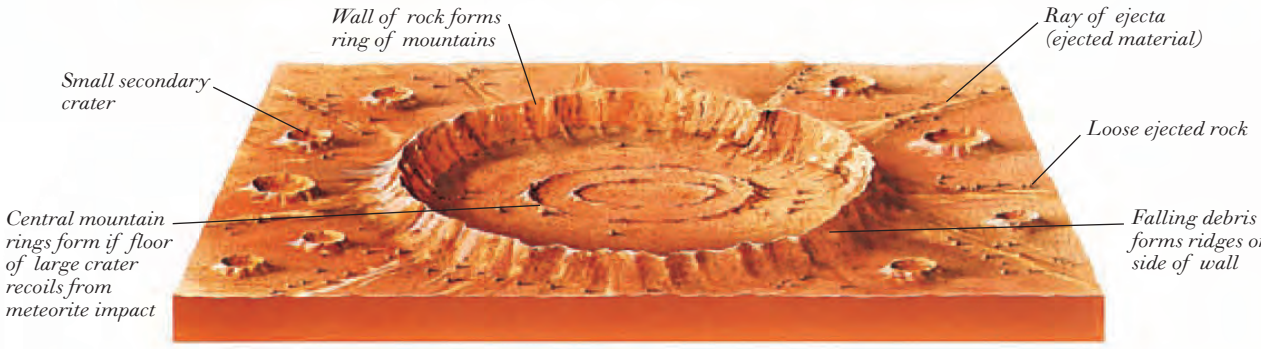
FORMATION OF A RAY CRATER



METEORITE IMPACT

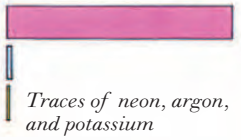


SECONDARY CRATERING



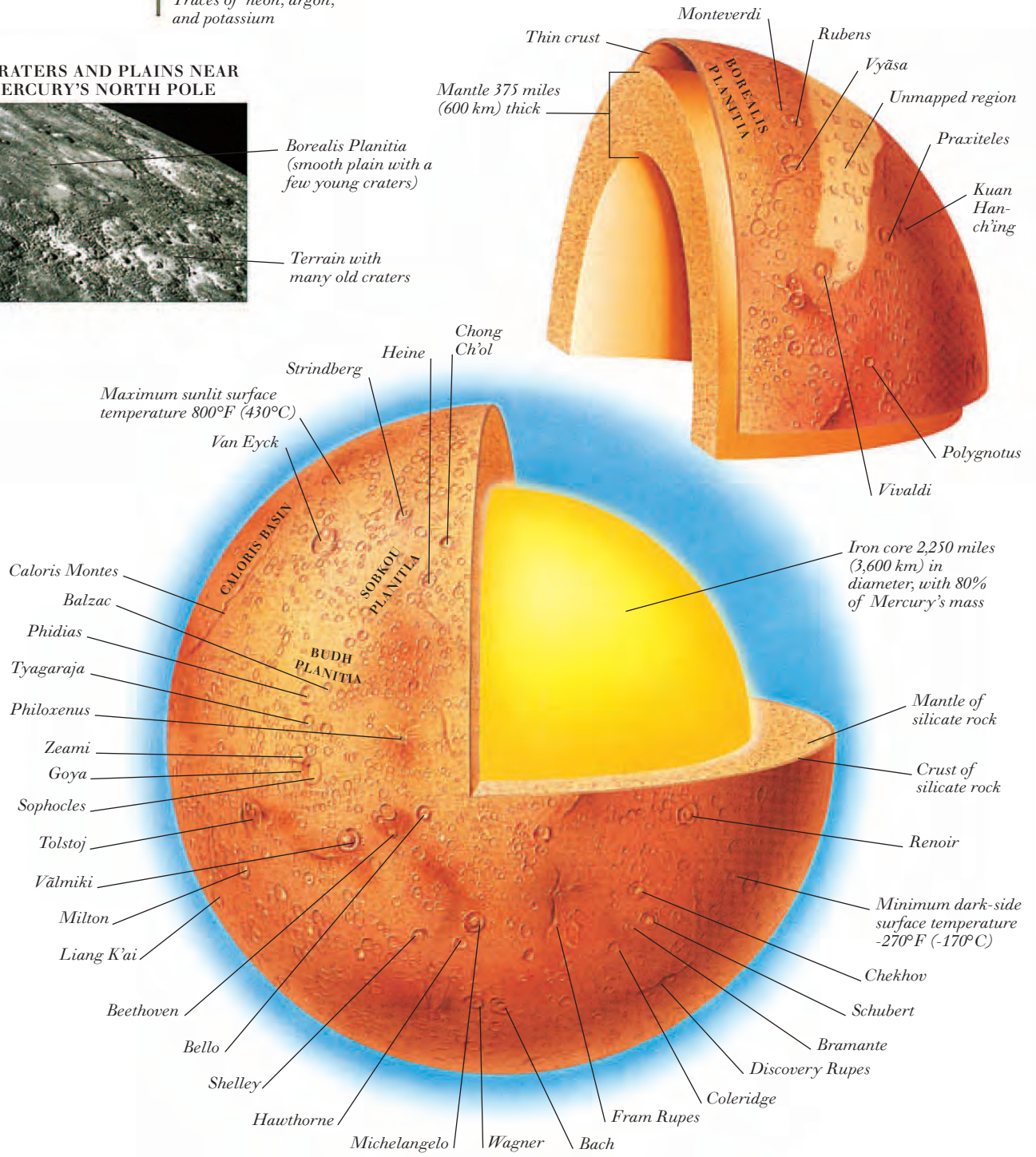
RAY CRATER

COMPOSITION OF ATMOSPHERE

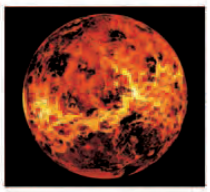


CRATERS AND PLAINS NEAR MERCURY'S NORTH POLE

EXTERNAL FEATURES AND INTERNAL STRUCTURE OF MERCURY



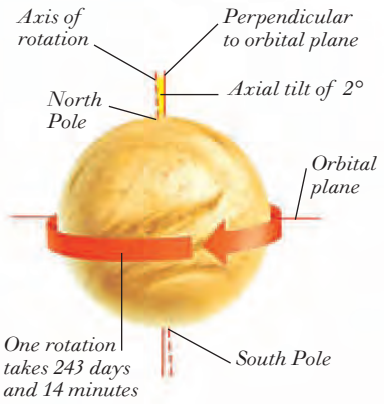
Venus



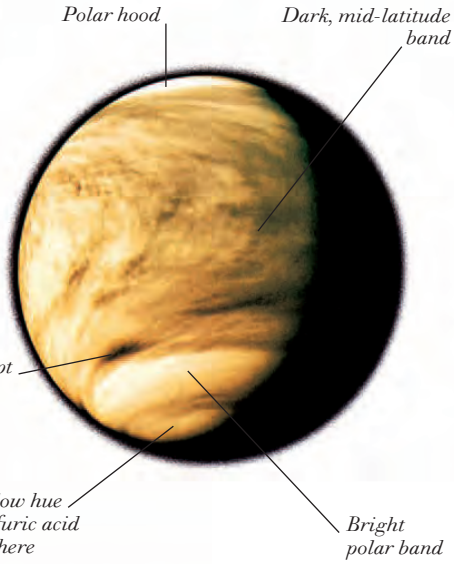
RADAR IMAGE OF VENUS

VENUS IS A ROCKY PLANET and the second planet from the Sun. Venus spins slowly backwards as it orbits the Sun, causing its rotational period to be the longest in the solar system, at about 243 Earth days. It is slightly smaller than Earth and probably has a similar internal structure, consisting of a semisolid metal core, surrounded by a rocky mantle and crust. Venus is the brightest object in the sky after the Sun and Moon because its clouds reflect sunlight strongly. The main component of the atmosphere is carbon dioxide, which traps heat in a greenhouse effect far stronger than that on Earth. As a result, Venus is the hottest planet, with a maximum surface temperature of about 900°F (480°C). The thick cloud layers contain droplets of sulfuric acid and are driven around the planet by winds at speeds of up to 220 miles (360 km) per hour. Although the planet takes 243 Earth days to rotate once, the high-speed winds cause the clouds to circle the planet in only four Earth days. The high temperature, acidic clouds, and enormous atmospheric pressure (about 90 times greater at the surface than that on Earth) make the environment extremely hostile. However, space probes have managed to land on Venus and photograph its dry, dusty surface. The Venusian surface has also been mapped by probes with radar equipment that can "see" through the cloud layers. Such radar maps reveal a terrain with craters, mountains, volcanoes, and areas where craters have been covered by plains of solidified volcanic lava. There are two large highland regions called Aphrodite Terra and Ishtar Terra.

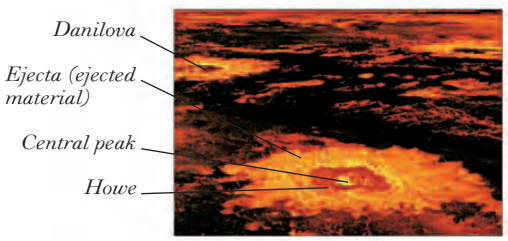
TILT AND ROTATION OF VENUS



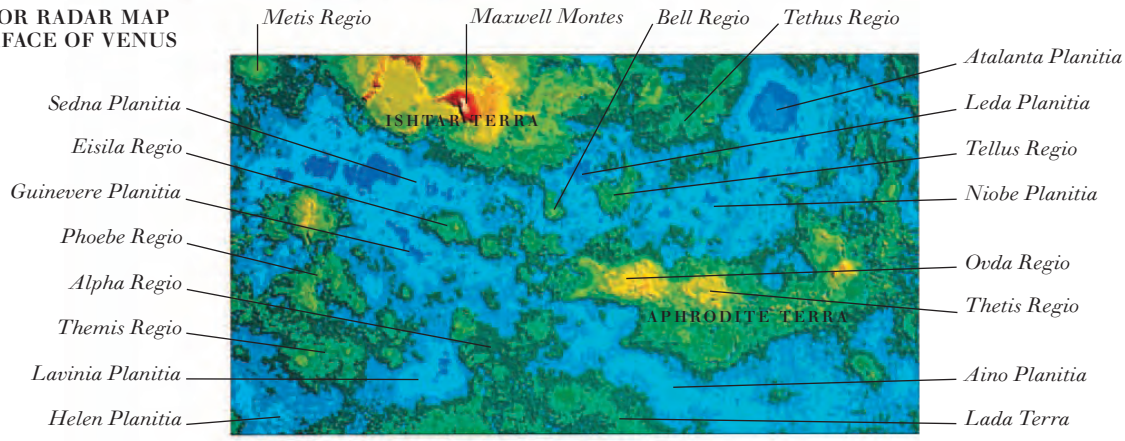
CLOUD FEATURES



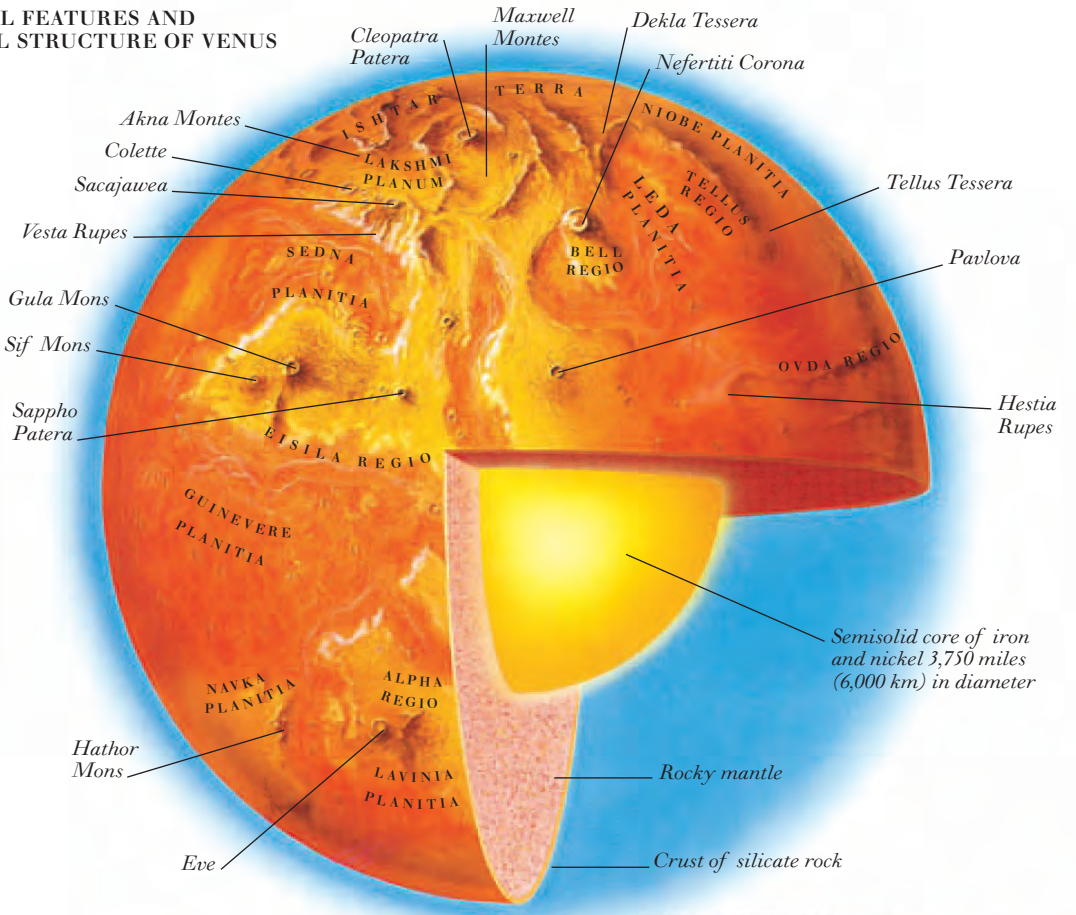
VENUSIAN CRATERS



FALSE-COLOR RADAR MAP OF THE SURFACE OF VENUS

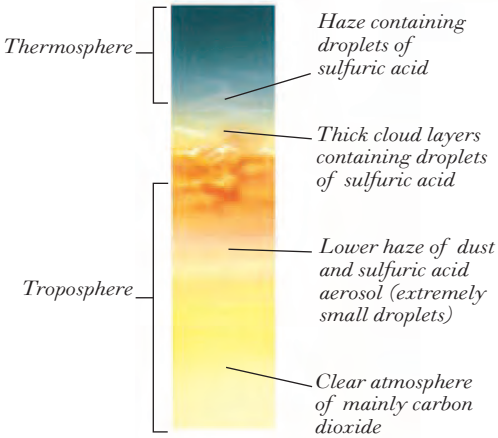


EXTERNAL FEATURES AND INTERNAL STRUCTURE OF VENUS

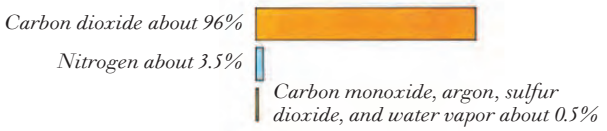


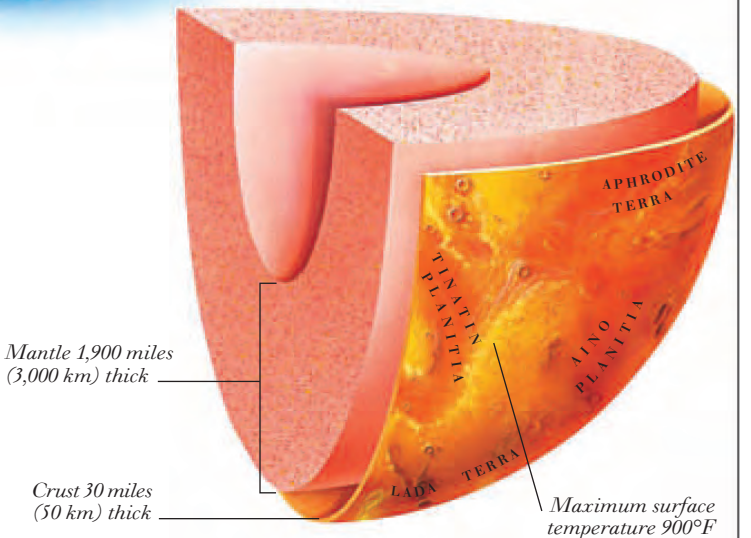
ATMOSPHERE

STRUCTURE

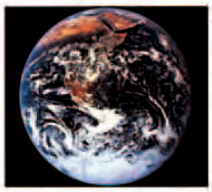


COMPOSITION





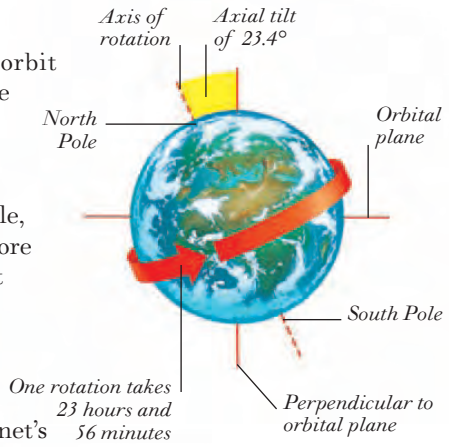
The Earth



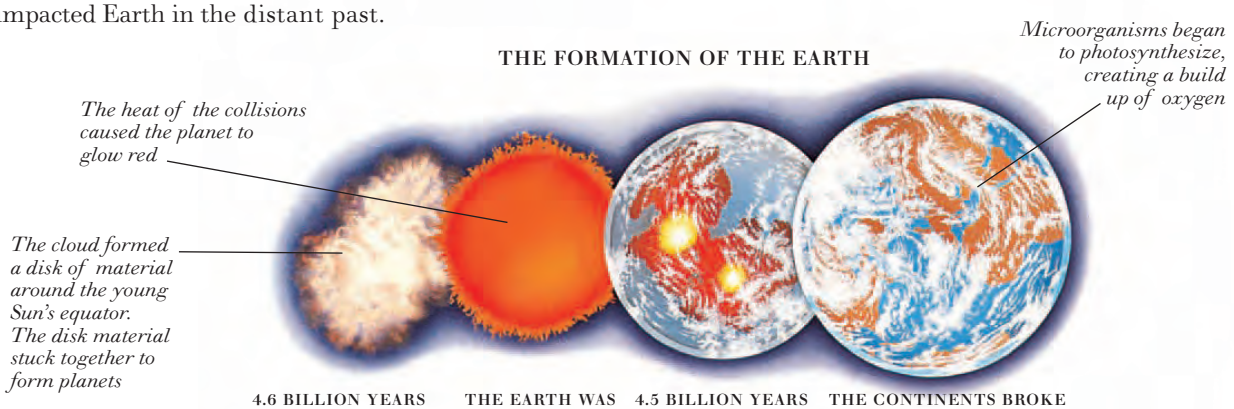
THE EARTH

THE EARTH IS THE THIRD of the eight planets that orbit the Sun. It is the largest and densest rocky planet, and the only one known to support life. About 70 percent of the Earth's surface is covered by water, which is not found in liquid form on the surface of any other planet. There are four main layers: the inner core, the outer core, the mantle, and the crust. At the heart of the planet the solid inner core has a temperature of about 11,900°F (6,600°C). The heat from this inner core causes material in the molten outer core and mantle to circulate in convection currents. It is thought that these convection currents generate the Earth's magnetic field, which extends into space as the magnetosphere. The Earth's atmosphere helps screen out some of the harmful radiation from the Sun, stops most meteoroids from reaching the planet's surface, and traps enough heat to prevent extremes of cold. The Earth has one natural satellite, the Moon, which is thought to have formed when a huge asteroid impacted Earth in the distant past.

TILT AND ROTATION OF THE EARTH



THE FORMATION OF THE EARTH

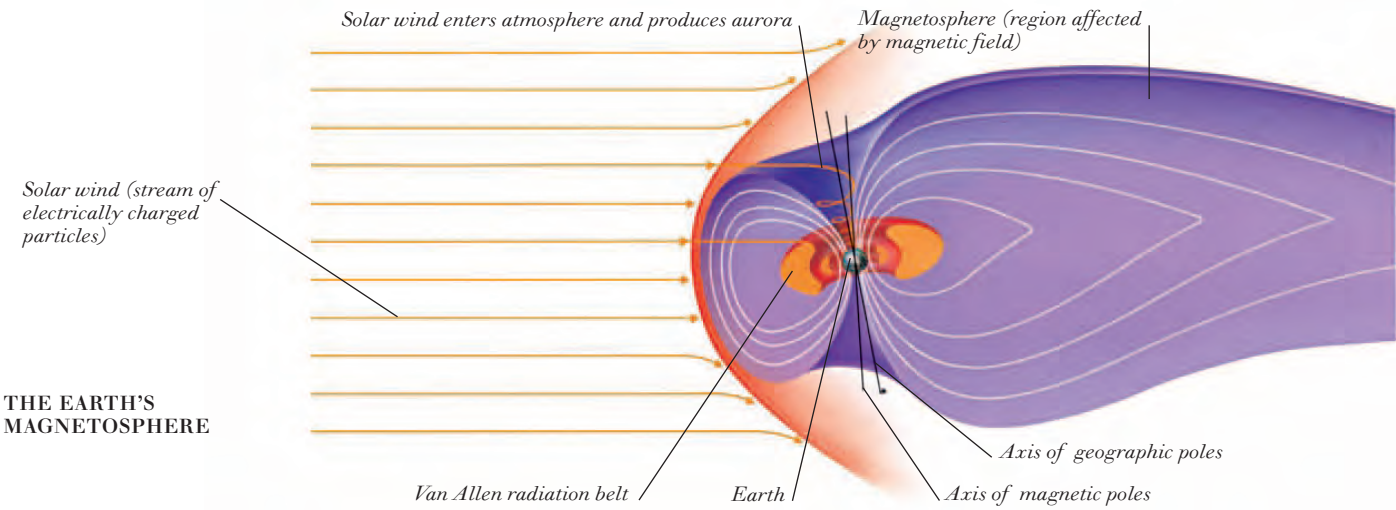


4.6 BILLION YEARS AGO, THE SOLAR SYSTEM FORMED FROM A CLOUD OF ROCK, ICE, AND GAS

THE EARTH WAS FORMED FROM COLLIDING ROCKS

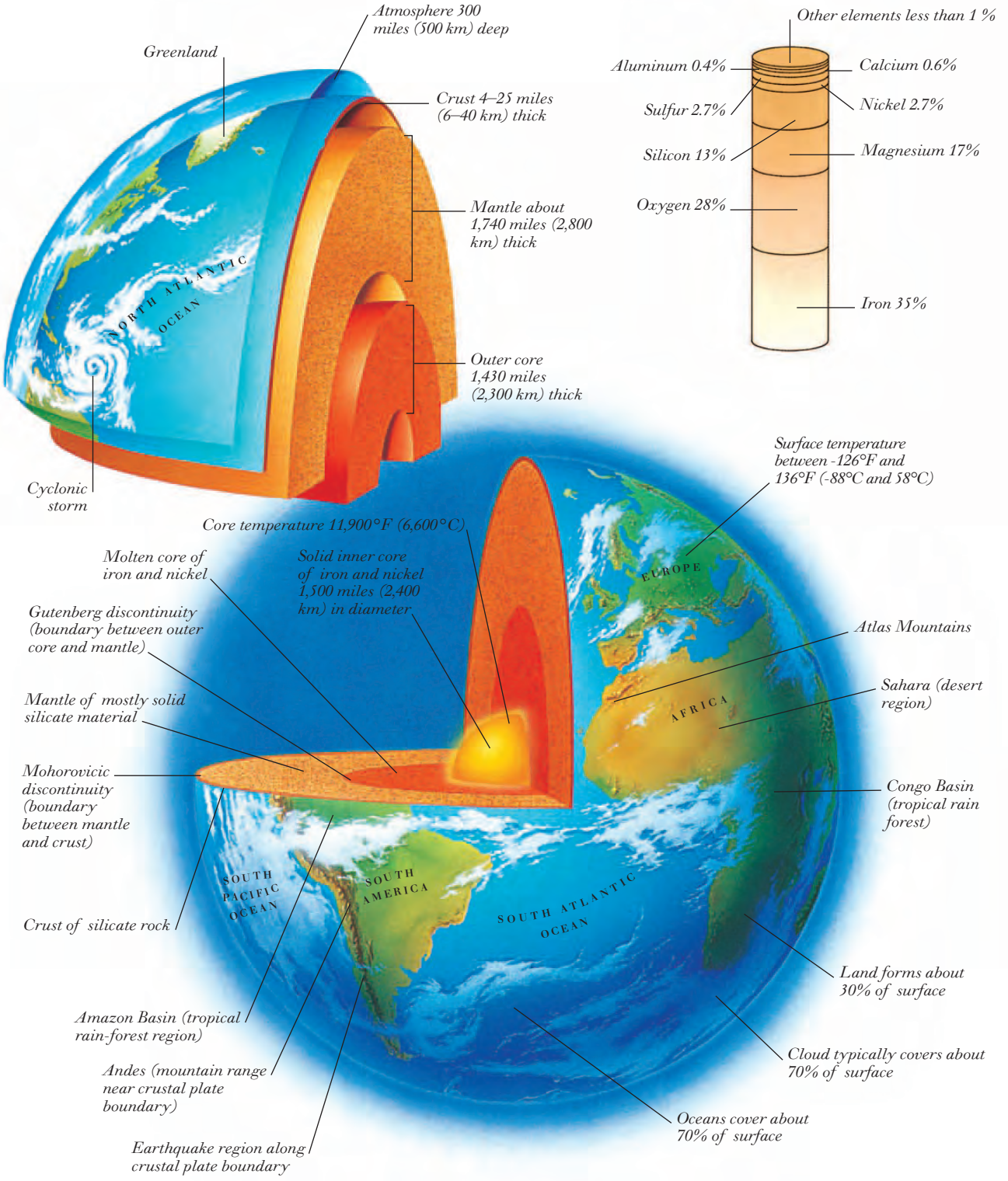
4.5 BILLION YEARS AGO THE SURFACE COOLED TO FORM THE CRUST

THE CONTINENTS BROKE UP AND REFORMED, GRADUALLY MOVING TO THEIR PRESENT POSITIONS



THE EARTH'S MAGNETOSPHERE

EXTERNAL FEATURES AND INTERNAL STRUCTURE OF THE EARTH



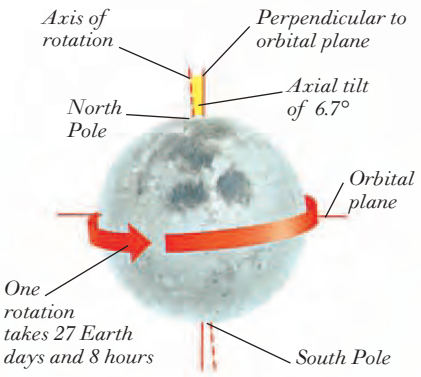
COMPOSITION OF THE EARTH

The Moon

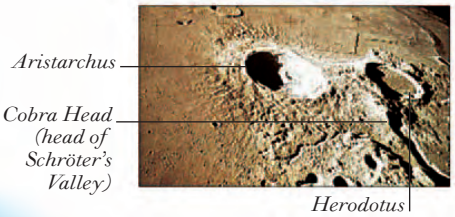
THE MOON FROM EARTH

THE MOON IS THE EARTH'S only natural satellite. It is relatively large for a moon, with a diameter of about 2,155 miles (3,470 km)—just over a quarter that of the Earth. The Moon takes the same time to rotate on its axis as it takes to orbit the Earth (27.3 days), and so the same side (the near side) always faces us. However, the amount of the surface we can see—the phase of the Moon—depends on how much of the near side is in sunlight. The Moon is dry and barren, with negligible atmosphere and water. It consists mainly of solid rock, although its core may contain molten rock or iron. The surface is dusty, with highlands covered in craters caused by meteorite impacts, and lowlands in which large craters have been filled by solidified lava to form dark areas called maria or "seas." Maria occur mainly on the near side, which has a thinner crust than the far side. Many of the craters are rimmed by mountain ranges that form the crater walls and can be thousands of feet high.

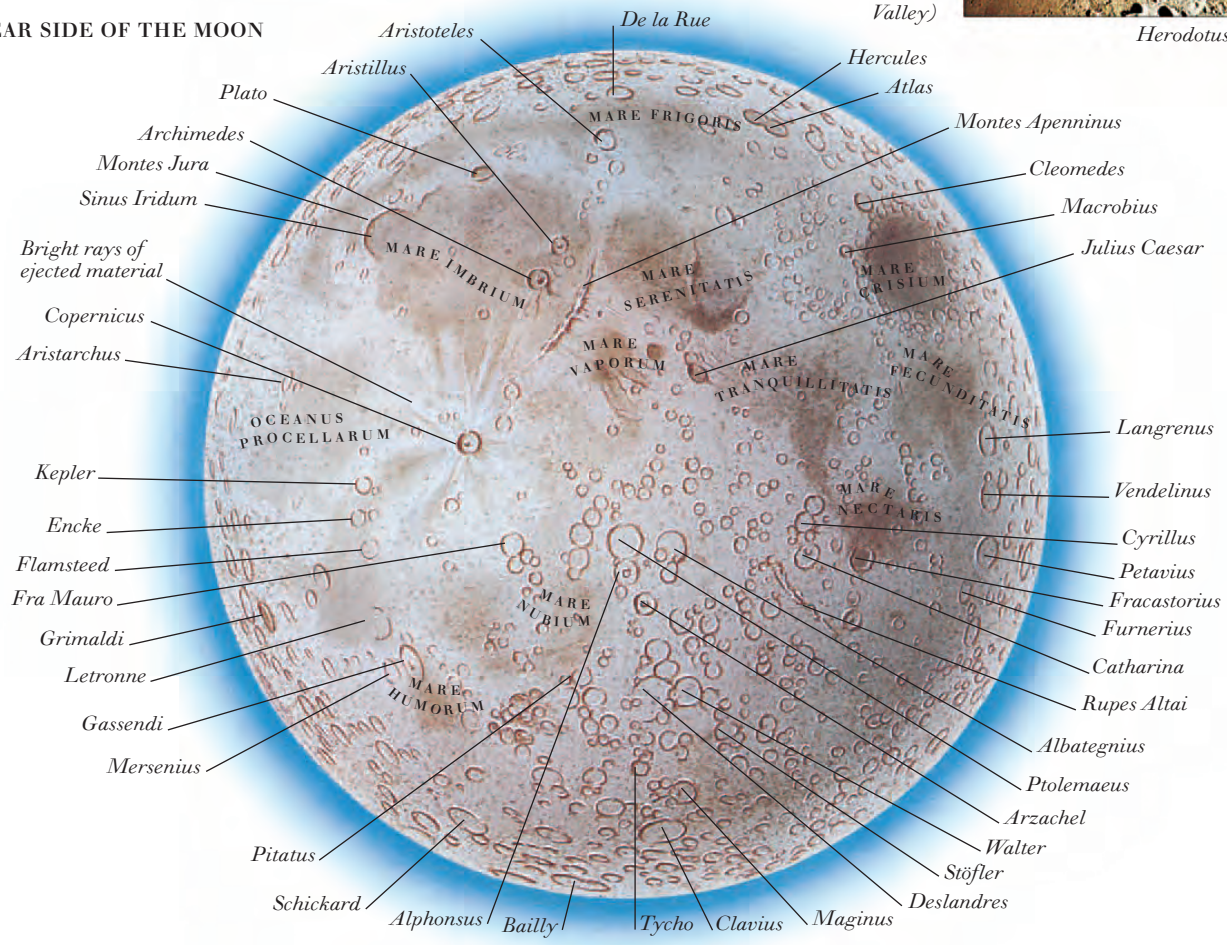
TILT AND ROTATION OF THE MOON

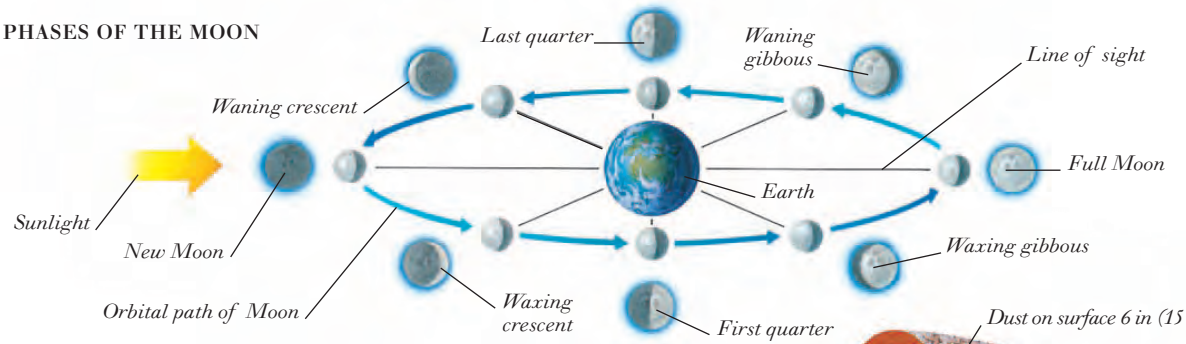


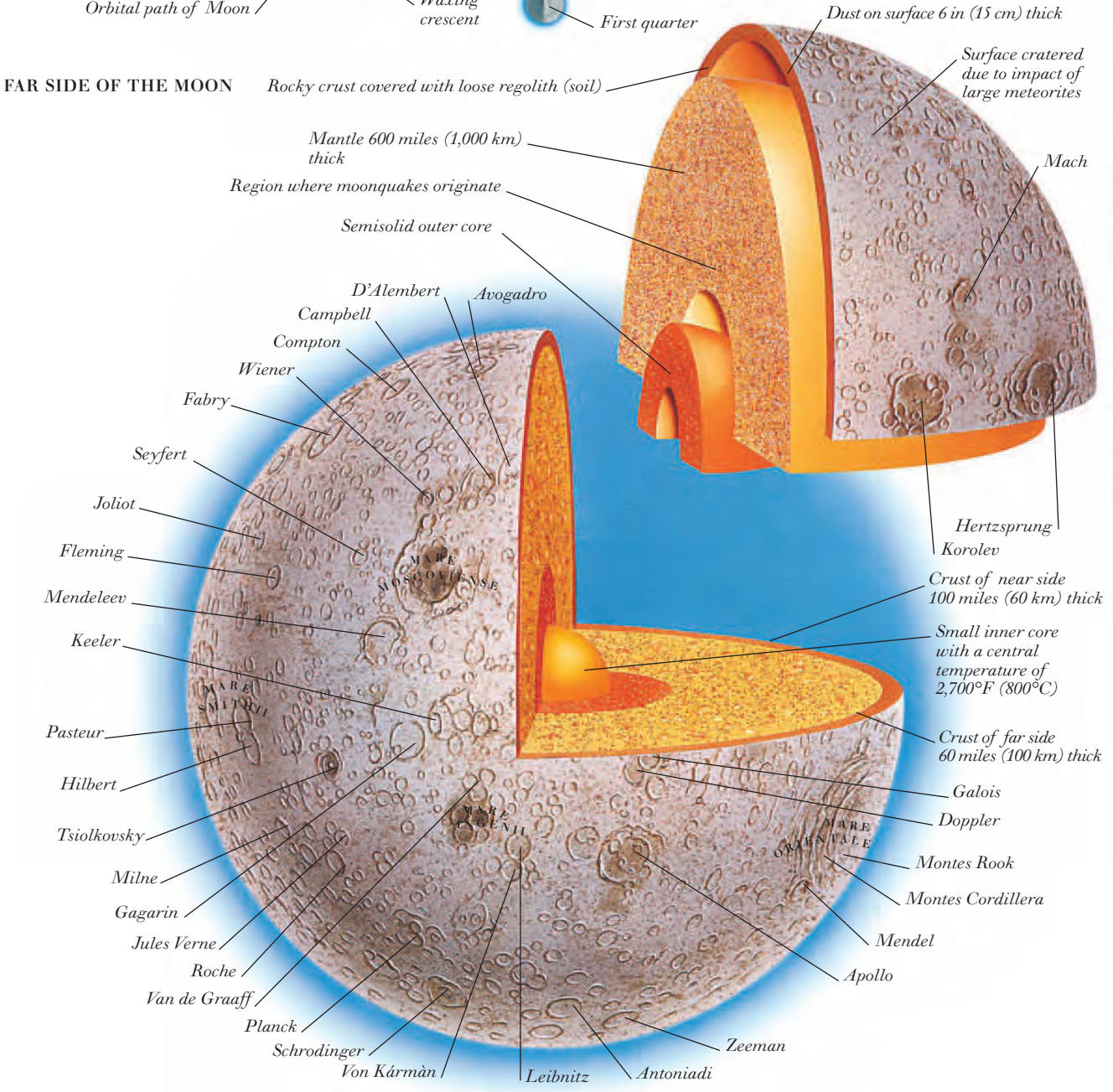
CRATERS ON OCEANUS PROCELLARUM



NEAR SIDE OF THE MOON




PHASES OF THE MOON
Last quarter
Waning gibbous
Line of sight
Waning crescent
Full Moon
Earth
Sunlight
New Moon
Waxing gibbous
Orbital path of Moon
Waxing crescent
First quarter

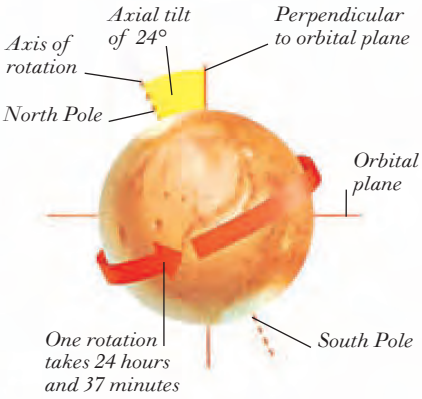

FAR SIDE OF THE MOON
Dust on surface 6 in (15 cm) thick
Rocky crust covered with loose regolith (soil)
Surface cratered due to impact of large meteorites
Mantle 600 miles (1,000 km) thick
Mach
Region where moonquakes originate
Semisolid outer core
D'Alembert
Avogadro
Campbell
Compton
Wiener
Fabry
Seyfert
Joliot
Fleming
Mendeleev
Keeler
Pasteur
Hilbert
Tsiolkovsky
Milne
Gagarin
Jules Verne
Roche
Van de Graaff
Planck
Schrodinger
Von Kármàn
Leibnitz
Antoniadi
Zeeman
Apollo
Mendel
Montes Cordillera
Montes Rook
Doppler
Galois
Crust of far side 60 miles (100 km) thick
Small inner core with a central temperature of 2,700°F (800°C)
Crust of near side 100 miles (60 km) thick
Korolev
Hertzsprung
MARE MOSCOVIENSE
MARE SMITHII
MARE CRISIUM
MARE ORIENTALE

Mars

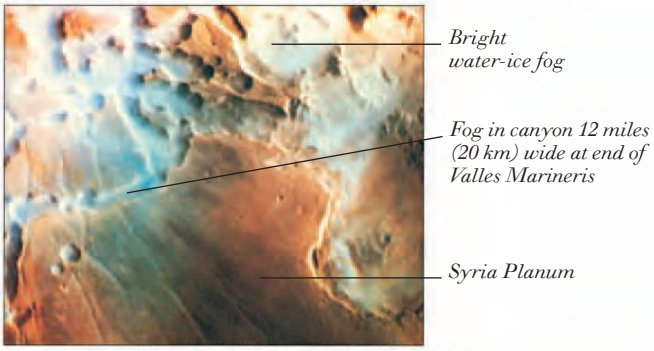
MARS

MARS, KNOWN AS THE RED PLANET, is the fourth planet from the Sun and the outermost rocky planet. In the 19th century, astronomers first observed what were thought to be signs of life on Mars. These signs included apparent canal-like lines on the surface, and dark patches that were thought to be vegetation. It is now known that the "canals" are an optical illusion, and the dark patches are areas where the red dust that covers most of the planet has been blown away. The fine dust particles are often whipped up by winds into dust storms that occasionally obscure almost all the surface. Residual fine dust in the atmosphere gives the Martian sky a pinkish hue. The northern hemisphere of Mars has many large plains formed of solidified volcanic lava, whereas the southern hemisphere has many craters and large impact basins. There are also several huge, extinct volcanoes, including Olympus Mons, which, at 370 miles (600 km) across and 15 miles (25 km) high, is the largest known volcano in the solar system. The surface also has many canyons and branching channels. The canyons were formed by movements of the surface crust, but the channels are thought to have been formed by flowing water that has now dried up. The Martian atmosphere is much thinner than Earth's, with only a few clouds and morning mists. Mars has two tiny, irregularly shaped moons called Phobos and Deimos. Their small size indicates that they may be asteroids that have been captured by the gravity of Mars.

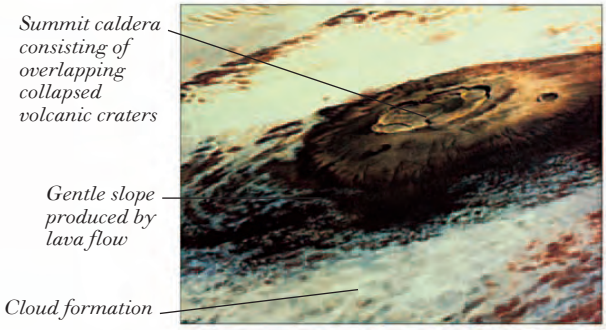
TILT AND ROTATION OF MARS



SURFACE FEATURES OF MARS

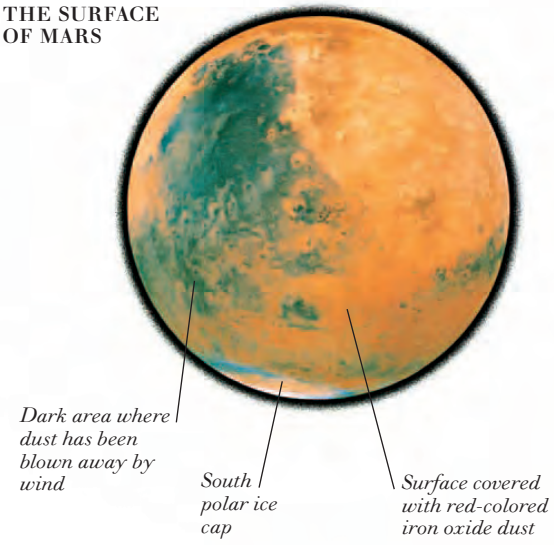


NOCTIS LABYRINTHUS (CANYON SYSTEM)



OLYMPUS MONS (EXTINCT SHIELD VOLCANO)

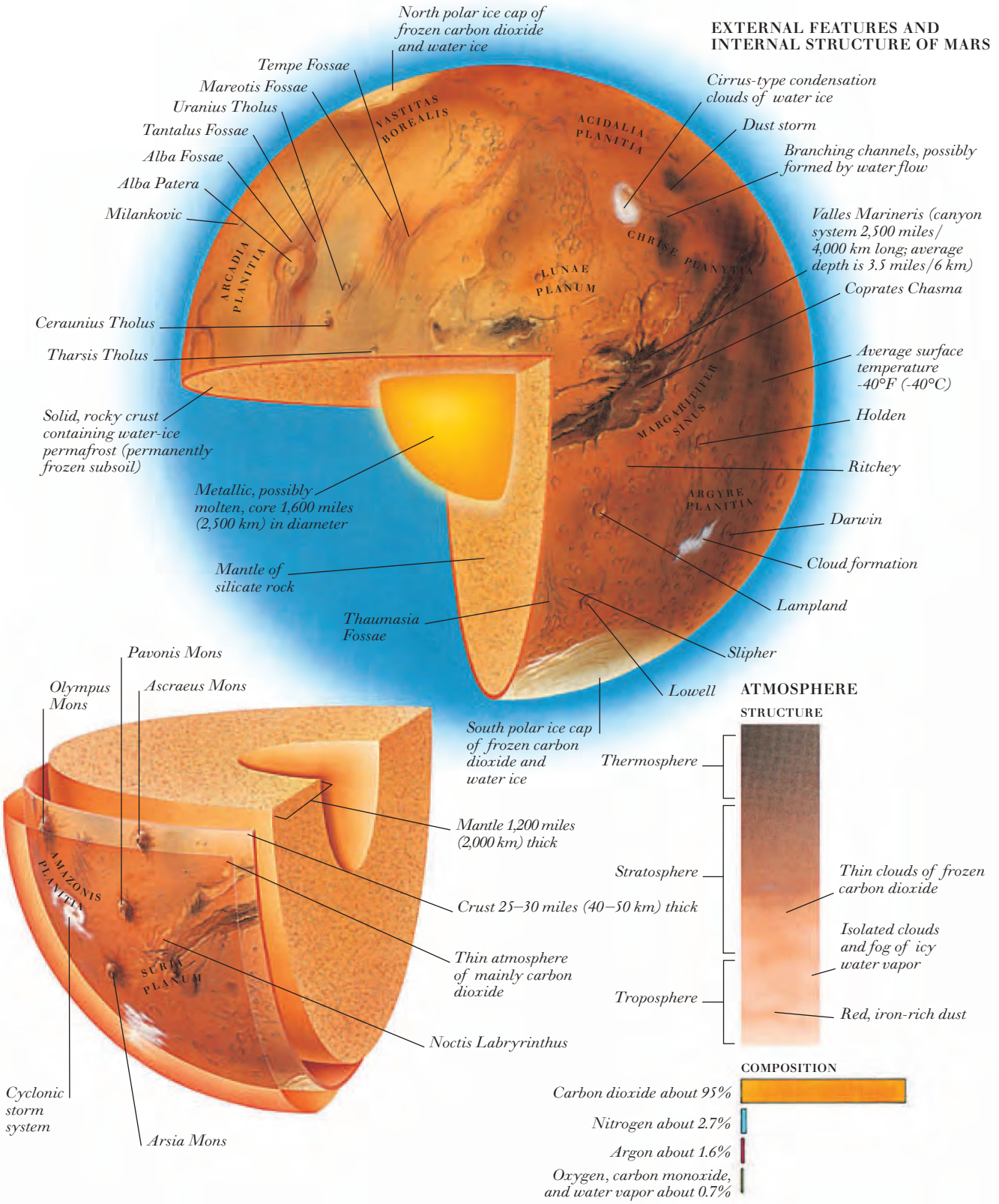
THE SURFACE OF MARS



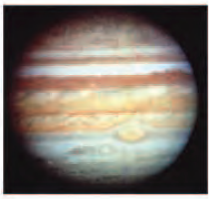
MOONS OF MARS

PHOBOS
Average diameter: 14 miles
Average distance from planet: 5,800 miles

DEIMOS
Average diameter: 8 miles
Average distance from planet: 14,600 miles


EXTERNAL FEATURES AND INTERNAL STRUCTURE OF MARS
North polar ice cap of frozen carbon dioxide and water ice
Tempe Fossae
Mareotis Fossae
Uranius Tholus
Tantalus Fossae
Alba Fossae
Alba Patera
Milankovic
VASTITAS BOREALIS
ACIDALIA PLANITIA
ARCADIA PLANITIA
CHRYSE PLANITIA
LUNAE PLANUM
Cirrus-type condensation clouds of water ice
Dust storm
Branching channels, possibly formed by water flow
Valles Marineris (canyon system 2,500 miles/ 4,000 km long; average depth is 3.5 miles/6 km)
Coprates Chasma
Ceraunius Tholus
Tharsis Tholus
Average surface temperature -40°F (-40°C)
MARGARITIFER SINUS
Holden
Solid, rocky crust containing water-ice permafrost (permanently frozen subsoil)
Ritchey
Metallic, possibly molten, core 1,600 miles (2,500 km) in diameter
ARGYRE PLANITIA
Darwin
Mantle of silicate rock
Cloud formation
Lampland
Thaumasia Fossae
Slipher
Lowell
Pavonis Mons
Olympus Mons
Ascraeus Mons
South polar ice cap of frozen carbon dioxide and water ice
ATMOSPHERE
STRUCTURE
Thermosphere
Mantle 1,200 miles (2,000 km) thick
Stratosphere
Thin clouds of frozen carbon dioxide
AMAZONIS PLANITIA
Crust 25–30 miles (40–50 km) thick
Isolated clouds and fog of icy water vapor
Thin atmosphere of mainly carbon dioxide
Troposphere
Red, iron-rich dust
SURIA PLANUM
Noctis Labryrinthus
COMPOSITION
Carbon dioxide about 95%
Nitrogen about 2.7%
Argon about 1.6%
Oxygen, carbon monoxide, and water vapor about 0.7%
Cyclonic storm system
Arsia Mons

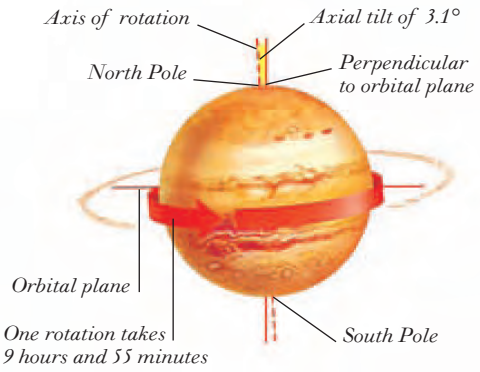
Jupiter



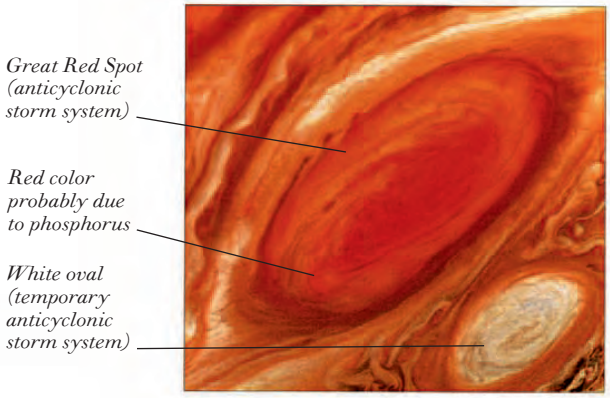
JUPITER

JUPITER IS THE FIFTH PLANET from the Sun and the innermost of the four giant planets. It is the largest and the most massive planet, with a diameter about 11 times that of the Earth and a mass about 2.5 times the combined mass of the seven other planets. Jupiter is thought to have a small rocky core surrounded by an inner mantle of metallic hydrogen (liquid hydrogen that acts like a metal). Outside the inner mantle is an outer mantle of liquid hydrogen and helium that merges into the gaseous atmosphere. Jupiter's rapid rate of rotation causes the clouds in its atmosphere to form belts and zones that encircle the planet parallel to the equator. Belts are dark, low-lying, relatively warm cloud layers, and zones are bright, high-altitude, cooler cloud layers. Within the belts and zones, turbulence causes the formation of cloud features such as white ovals and red spots, both of which are huge storm systems. The most prominent cloud feature is a storm called the Great Red Spot, which consists of a spiraling column of clouds three times wider than the Earth that rises about five miles (8 km) above the upper cloud layer. Jupiter has a thin, faint, main ring, inside which is a tenuous halo ring of tiny particles. Beyond the main ring's outer edge is a broad and faint two-part gossamer ring. There are 63 known Jovian moons. The four largest moons (called the Galileans) are Ganymede, Callisto, Io, and Europa. Ganymede and Callisto are cratered and icy. Europa is smooth and icy and is thought to have a subsurface water ocean. Io is covered in bright red, orange, and yellow splotches. This coloring is caused by sulfurous material from active volcanoes that shoot plumes of lava hundreds of miles above the surface.

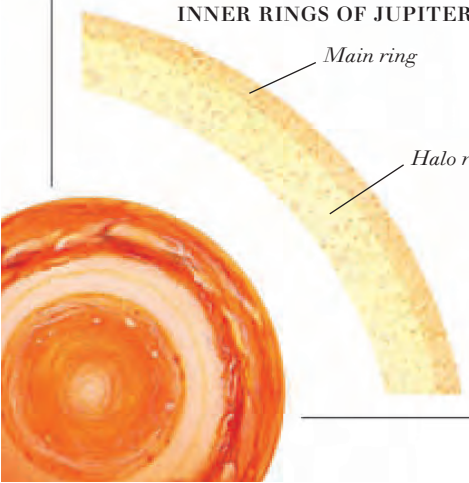
TILT AND ROTATION OF JUPITER



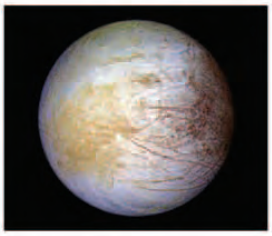
GREAT RED SPOT AND WHITE OVAL



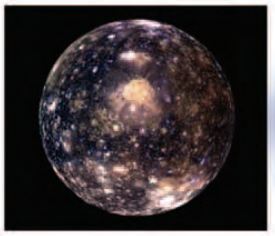
INNER RINGS OF JUPITER



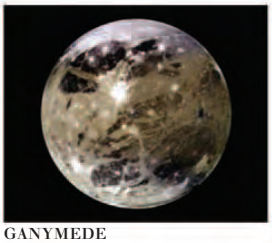
GALILEAN MOONS OF JUPITER



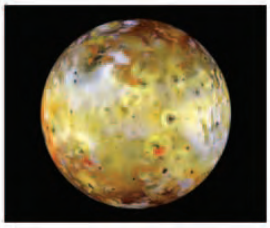
EUROPA
Diameter: 1,950 miles
Average distance from planet: 416,900 miles



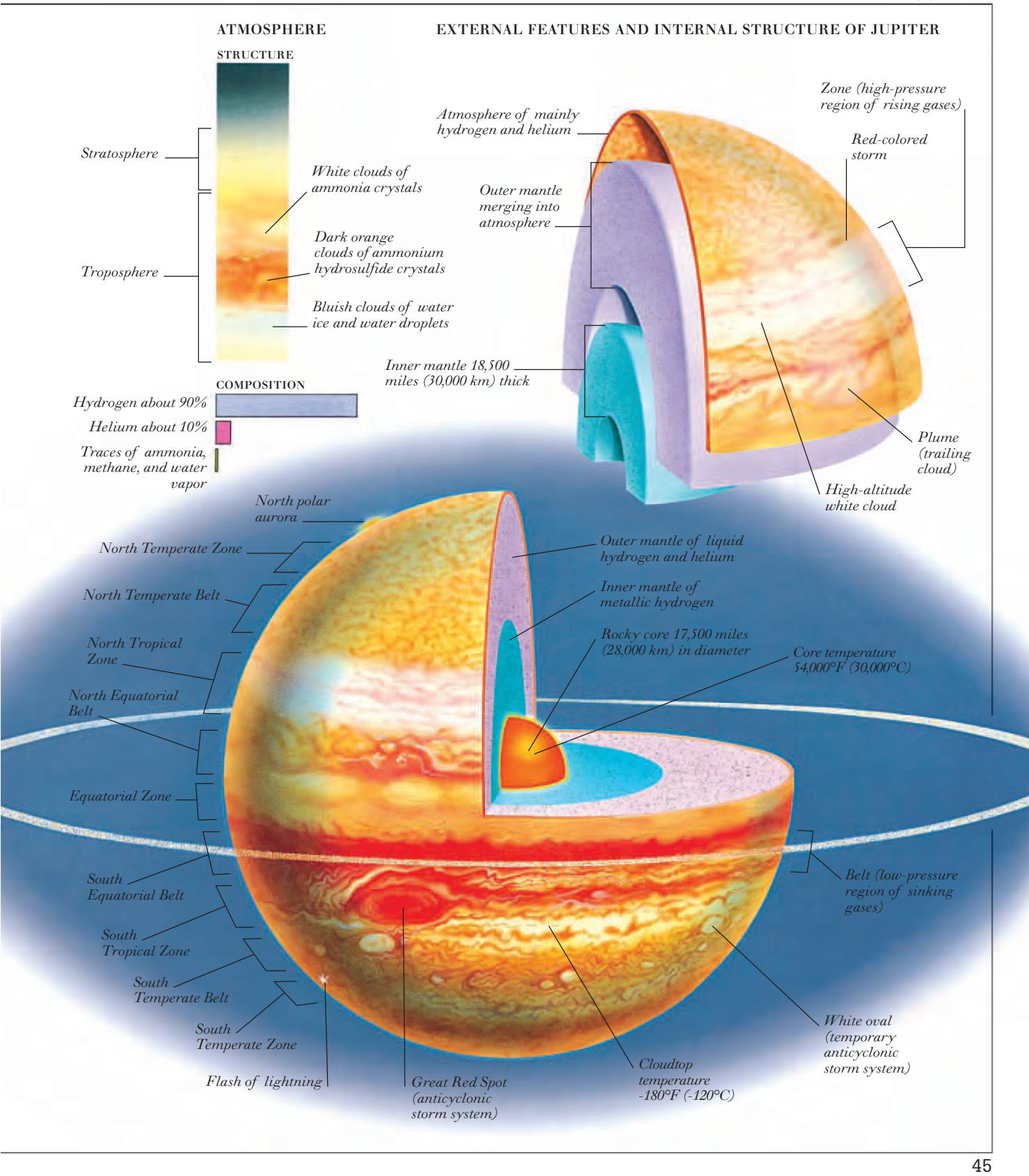
CALLISTO
Diameter: 2,983 miles
Average distance from planet: 1,168,200 miles



GANYMEDE
Diameter: 3,270 miles
Average distance from planet: 664,900 miles



IO
Diameter: 2,263 miles
Average distance from planet: 262,100 miles

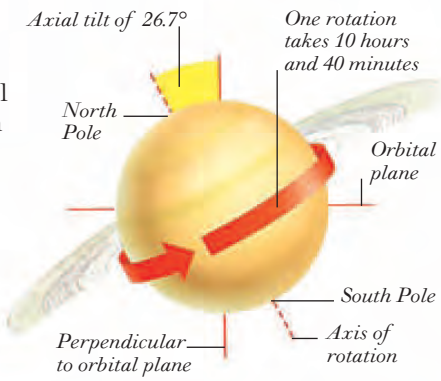

ATMOSPHERE
STRUCTURE
Stratosphere
Troposphere
White clouds of ammonia crystals
Dark orange clouds of ammonium hydrosulfide crystals
Bluish clouds of water ice and water droplets
COMPOSITION
Hydrogen about 90%
Helium about 10%
Traces of ammonia, methane, and water vapor
EXTERNAL FEATURES AND INTERNAL STRUCTURE OF JUPITER
Atmosphere of mainly hydrogen and helium
Outer mantle merging into atmosphere
Zone (high-pressure region of rising gases)
Red-colored storm
Inner mantle 18,500 miles (30,000 km) thick
Plume (trailing cloud)
High-altitude white cloud
North polar aurora
North Temperate Zone
North Temperate Belt
North Tropical Zone
North Equatorial Belt
Equatorial Zone
South Equatorial Belt
South Tropical Zone
South Temperate Belt
South Temperate Zone
Flash of lightning
Great Red Spot (anticyclonic storm system)
Cloudtop temperature -180°F (-120°C)
White oval (temporary anticyclonic storm system)
Belt (low-pressure region of sinking gases)
Outer mantle of liquid hydrogen and helium
Inner mantle of metallic hydrogen
Rocky core 17,500 miles (28,000 km) in diameter
Core temperature 54,000°F (30,000°C)

Saturn

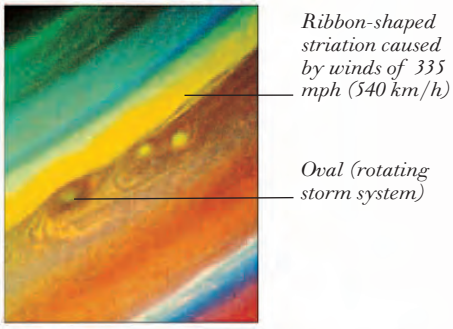
FALSE-COLOR IMAGE OF SATURN

SATURN IS THE SIXTH PLANET from the Sun. It is a gas giant almost as big as Jupiter, with an equatorial diameter of about 75,000 miles (120,500 km). Saturn is thought to consist of a small core of rock and ice surrounded by an inner mantle of metallic hydrogen (liquid hydrogen that acts like a metal). Outside the inner mantle is an outer mantle of liquid hydrogen that merges into a gaseous atmosphere. Saturn's clouds form belts and zones similar to those on Jupiter, but obscured by overlying haze. Storms and eddies, seen as red or white ovals, occur in the clouds. Saturn has an extremely thin but wide system of rings that is about half a mile (1 km) thick but extends outward to about 260,000 miles (420,000 km) from the planet's surface. The main rings comprise thousands of narrow ringlets, each made of icy rock lumps that range in size from tiny particles to chunks several yards across. The D, E, and G rings are very faint, the F ring is brighter, and the A, B, and C rings are bright enough to be seen from Earth with binoculars. In 2009, a huge dust ring was discovered 4 million miles (6 million km) beyond the main system. Saturn has more than 60 known moons, some of which orbit inside the rings and are thought to exert a gravitational influence on the shapes of the rings. Unusually, seven of the moons are co-orbital—they share an orbit with another moon. Astronomers believe that such co-orbital moons may have originated from a single satellite that broke up.

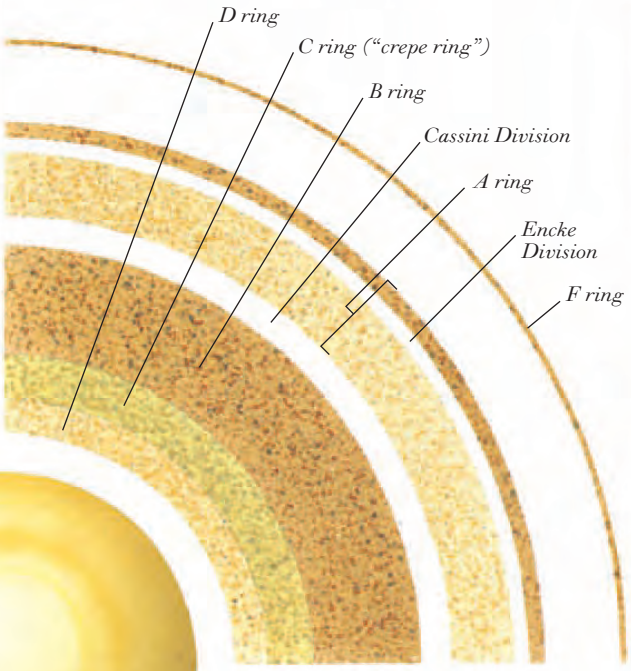
TILT AND ROTATION OF SATURN



FALSE-COLOR IMAGE OF SATURN'S CLOUD FEATURES



INNER RINGS OF SATURN



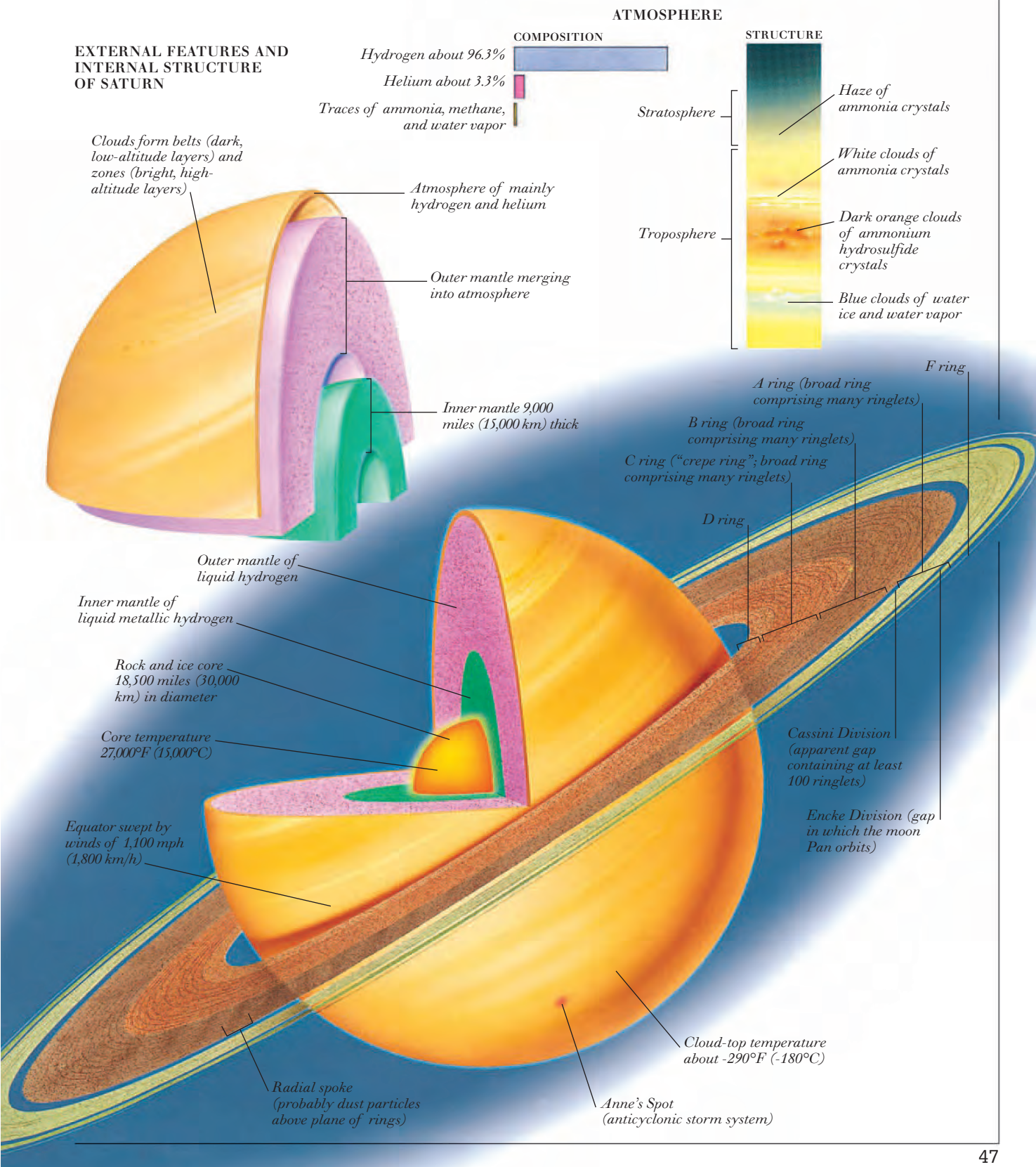
MOONS OF SATURN

ENCELADUS
Diameter: 509 miles
Average distance from planet: 148,000 miles

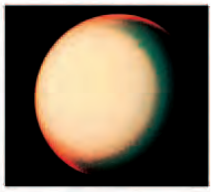
TETHYS
Diameter: 652 miles
Average distance from planet: 183,000 miles

DIONE
Diameter: 695 miles
Average distance from planet: 254,000 miles

MIMAS
Diameter: 247 miles
Average distance from planet: 115,600 miles


EXTERNAL FEATURES AND INTERNAL STRUCTURE OF SATURN
ATMOSPHERE
COMPOSITION
Hydrogen about 96.3%
Helium about 3.3%
Traces of ammonia, methane, and water vapor
STRUCTURE
Stratosphere
Troposphere
Haze of ammonia crystals
White clouds of ammonia crystals
Dark orange clouds of ammonium hydrosulfide crystals
Blue clouds of water ice and water vapor
Clouds form belts (dark, low-altitude layers) and zones (bright, high-altitude layers)
Atmosphere of mainly hydrogen and helium
Outer mantle merging into atmosphere
Inner mantle 9,000 miles (15,000 km) thick
F ring
A ring (broad ring comprising many ringlets)
B ring (broad ring comprising many ringlets)
C ring ("crepe ring"; broad ring comprising many ringlets)
D ring
Outer mantle of liquid hydrogen
Inner mantle of liquid metallic hydrogen
Rock and ice core 18,500 miles (30,000 km) in diameter
Core temperature 27,000°F (15,000°C)
Cassini Division (apparent gap containing at least 100 ringlets)
Encke Division (gap in which the moon Pan orbits)
Equator swept by winds of 1,100 mph (1,800 km/h)
Cloud-top temperature about -290°F (-180°C)
Radial spoke (probably dust particles above plane of rings)
Anne's Spot (anticyclonic storm system)

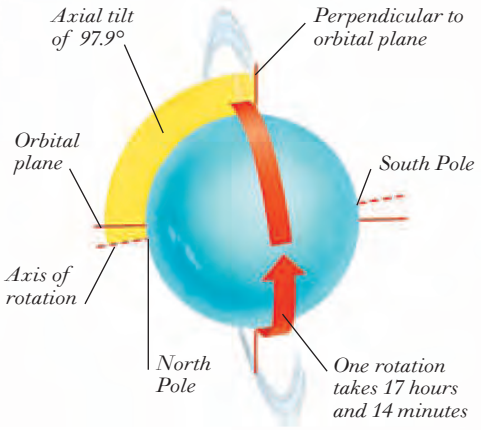
Uranus



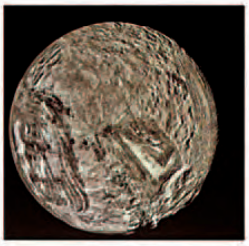
FALSE-COLOR IMAGE OF URANUS

URANUS IS THE SEVENTH PLANET from the Sun and the third largest, with a diameter of about 32,000 miles (51,000 km). It is thought to consist of a dense mixture of different types of ice and gas around a solid core. Its atmosphere contains traces of methane, giving the planet a blue-green hue, and the temperature at the cloud tops is about -350°F (-210°C). Uranus is the most featureless planet to have been closely observed: only a few icy clouds of methane have been seen so far. Uranus is unique among the planets in that its axis of rotation lies close to its orbital plane. As a result of its strongly tilted rotational axis, Uranus rolls on its side along its orbital path around the Sun, whereas other planets spin more or less upright. Uranus is encircled by main rings that consist of rocks interspersed with dust lanes and two distant outer rings made of dust. The rings contain some of the darkest matter in the solar system and are extremely narrow, making them difficult to detect: most of them are less than 6 miles (10 km) wide, whereas most of Saturn's rings are thousands of miles in width. There are 27 known Uranian moons, all of which are icy and most of which are farther out than the rings. The 13 inner moons are small and dark, with diameters of less than 100 miles (160 km), and the five major moons are between about 290 and 1,000 miles (470 and 1,600 km) in diameter. The major moons have a wide variety of surface features. Miranda has the most varied surface, with cratered areas broken up by huge ridges and cliffs 12 miles (20 km) high. Beyond these are nine much more distant moons with diameters less than 90 miles (150 km).

TILT AND ROTATION OF URANUS

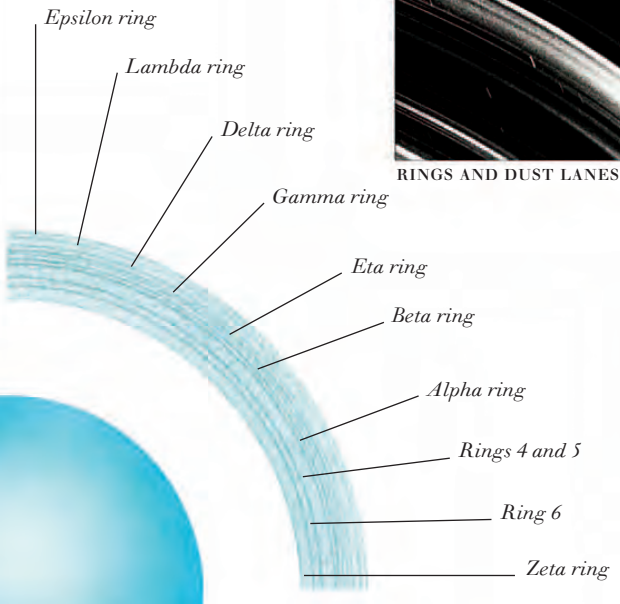


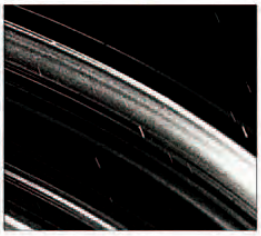
MAJOR MOONS



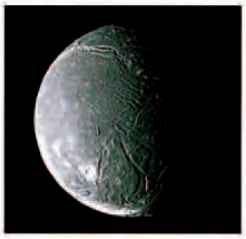
MIRANDA
Diameter: 295 miles
Average distance from planet: 80,700 miles

RINGS OF URANUS





RINGS AND DUST LANES

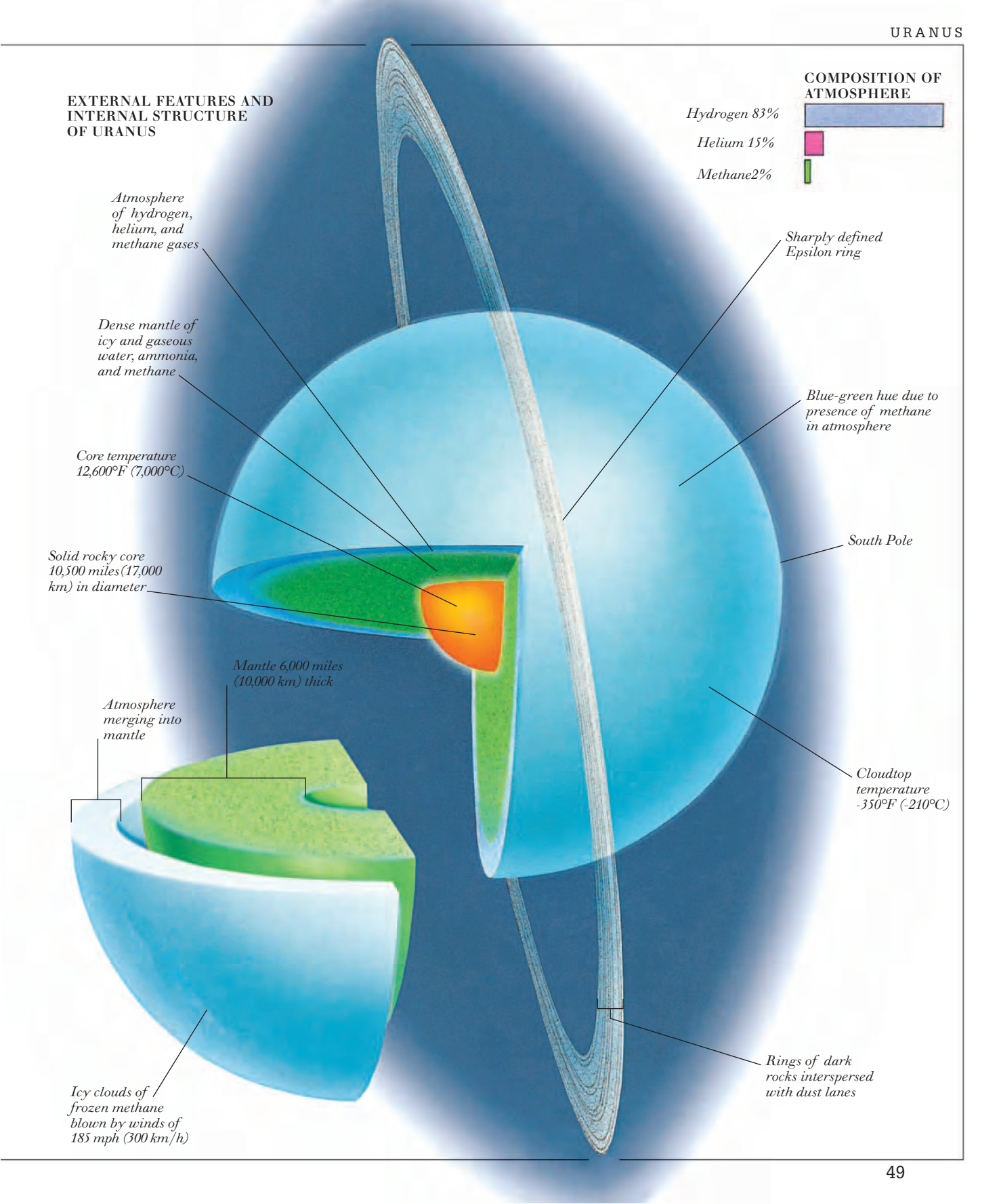


ARIEL
Diameter: 720 miles
Average distance from planet: 118,800 miles

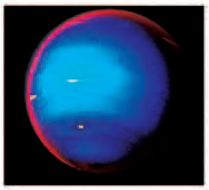
TITANIA
Diameter: 981 miles
Average distance from planet: 270,900 miles

UMBRIEL
Diameter: 726 miles
Average distance from planet: 165,500 miles

OBERON
Diameter: 946 miles
Average distance from planet: 362,000 miles


EXTERNAL FEATURES AND INTERNAL STRUCTURE OF URANUS
COMPOSITION OF ATMOSPHERE
Hydrogen 83%
Helium 15%
Methane2%
Atmosphere of hydrogen, helium, and methane gases
Sharply defined Epsilon ring
Dense mantle of icy and gaseous water, ammonia, and methane
Blue-green hue due to presence of methane in atmosphere
Core temperature 12,600°F (7,000°C)
South Pole
Solid rocky core 10,500 miles (17,000 km) in diameter
Mantle 6,000 miles (10,000 km) thick
Atmosphere merging into mantle
Cloudtop temperature -350°F (-210°C)
Rings of dark rocks interspersed with dust lanes
Icy clouds of frozen methane blown by winds of 185 mph (300 km/h)

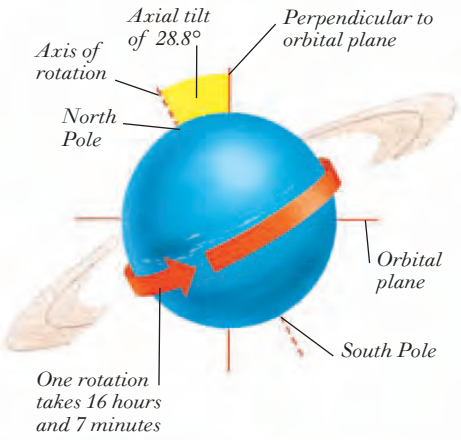
Neptune and Pluto



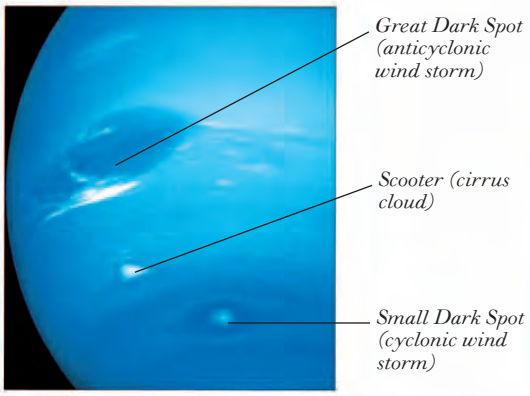
FALSE-COLOR IMAGE OF NEPTUNE

NEPTUNE IS the farthest planet from the Sun, at an average distance of about 2.8 billion miles (4.5 billion km). Neptune is the smallest of the giant planets and is thought to consist of a small rocky core surrounded by a mixture of liquids and gases. Several transient cloud features have been observed in its atmosphere. The largest of these were the Great Dark Spot, which was as wide as the Earth, the Small Dark Spot, and the Scooter. The Great and Small Dark Spots were huge storms that were swept around the planet by winds of about 1,200 miles (2,000 km) per hour. The Scooter was a large area of cirrus cloud. Neptune has six tenuous rings and 13 known moons. Triton is the largest Neptunian moon and the coldest object in the solar system, with a temperature of -390°F (-240°C). Unlike most moons in the solar system, Triton orbits its mother planet in the opposite direction of the planet's rotation. The region extending out from Neptune's orbit is populated by Kuiper Belt objects and dwarf planets. They make a doughnut-shaped belt called the Kuiper Belt. The Kuiper Belt objects are a mix of rock and ice, irregular in shape, and less than 600 miles (1,000 km) across. The larger dwarf planets, which include Pluto, are almost round bodies. Pluto was the first object discovered beyond Neptune and was considered a planet until the dwarf planet category was introduced in 2006. It is made of rock and ice and is 1,365 miles (2,274 km) across. It has three known moons. The largest, Charon, is about half Pluto's size and the two probably had a common origin.

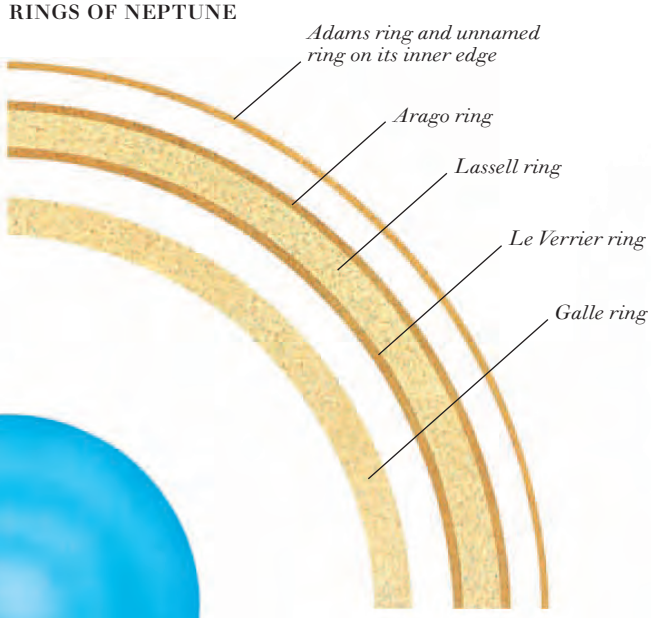
TILT AND ROTATION OF NEPTUNE



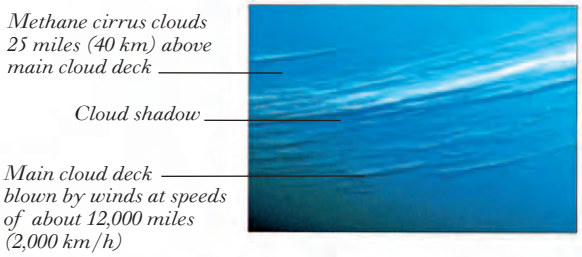
CLOUD FEATURES OF NEPTUNE



RINGS OF NEPTUNE

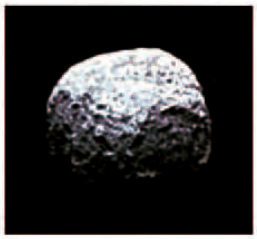


HIGH-ALTITUDE CLOUDS

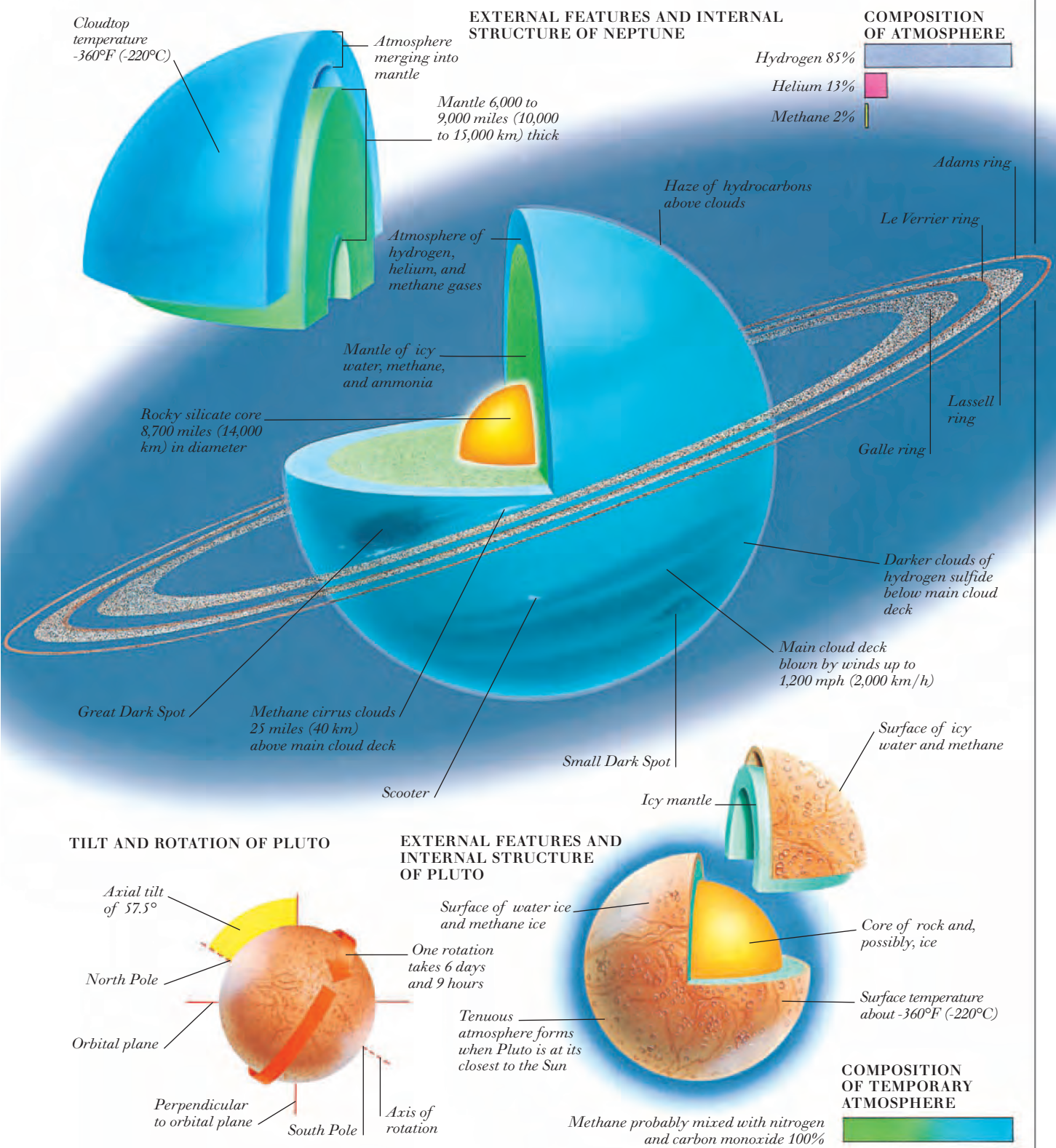


MOONS OF NEPTUNE

TRITON
Diameter: 1,681 miles
Average distance from planet: 220,500 miles



PROTEUS
Diameter: 259 miles
Average distance from planet: 73,100 miles


EXTERNAL FEATURES AND INTERNAL STRUCTURE OF NEPTUNE
COMPOSITION OF ATMOSPHERE
Hydrogen 85%
Helium 13%
Methane 2%
Cloudtop temperature -360°F (-220°C)
Atmosphere merging into mantle
Mantle 6,000 to 9,000 miles (10,000 to 15,000 km) thick
Haze of hydrocarbons above clouds
Adams ring
Le Verrier ring
Atmosphere of hydrogen, helium, and methane gases
Mantle of icy water, methane, and ammonia
Rocky silicate core 8,700 miles (14,000 km) in diameter
Lassell ring
Galle ring
Darker clouds of hydrogen sulfide below main cloud deck
Main cloud deck blown by winds up to 1,200 mph (2,000 km/h)
Great Dark Spot
Methane cirrus clouds 25 miles (40 km) above main cloud deck
Scooter
Small Dark Spot
Surface of icy water and methane
Icy mantle
TILT AND ROTATION OF PLUTO
Axial tilt of 57.5°
North Pole
One rotation takes 6 days and 9 hours
Orbital plane
Perpendicular to orbital plane
South Pole
Axis of rotation
EXTERNAL FEATURES AND INTERNAL STRUCTURE OF PLUTO
Surface of water ice and methane ice
Core of rock and, possibly, ice
Surface temperature about -360°F (-220°C)
Tenuous atmosphere forms when Pluto is at its closest to the Sun
COMPOSITION OF TEMPORARY ATMOSPHERE
Methane probably mixed with nitrogen and carbon monoxide 100%

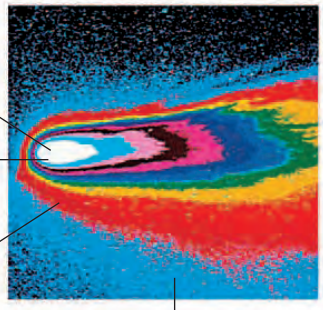
Asteroids, comets, and meteoroids

ASTEROID 951 GASPRA

ASTEROIDS, COMETS, AND METEOROIDS are all debris remaining from the nebula from which the solar system formed 4.6 billion years ago. Asteroids are rocky bodies up to about 600 miles (1,000 km) in diameter, although most are much smaller. Most of them orbit the Sun in the asteroid belt, which lies between the orbits of Mars and Jupiter. Cometary nuclei exist in a huge cloud (called the Oort Cloud) that surrounds the planetary part of the solar system. They are made of frozen water and dust and are a few miles in diameter. Occasionally, a comet is deflected from the Oort Cloud on to a long, elliptical path that brings it much closer to the Sun. As the comet approaches the Sun, the cometary nucleus starts to vaporize in the heat, producing both a brightly shining coma (a huge sphere of gas and dust around the nucleus), and a gas tail, and a dust tail. Meteoroids are small chunks of stone or stone and iron, which are fragments of asteroids or comets. Meteoroids range in size from tiny dust particles to objects tens of meters across. If a meteoroid enters the Earth's atmosphere, it is heated by friction and appears as a glowing streak of light called a meteor (also known as a shooting star). Meteor showers occur when the Earth passes through the trail of dust particles left by a comet. Most meteoroids burn up in the atmosphere. The remnants of the few that are large enough to reach the Earth's surface are termed meteorites.

OPTICAL IMAGE OF HALLEY'S COMET

FALSE-COLOR IMAGE OF HALLEY'S COMET



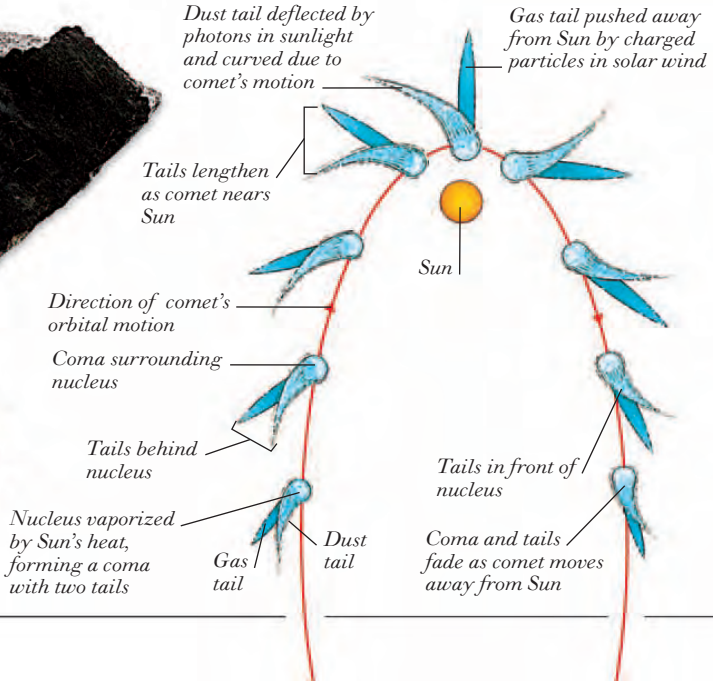
FALSE-COLOR IMAGE OF A LEONID METEOR SHOWER

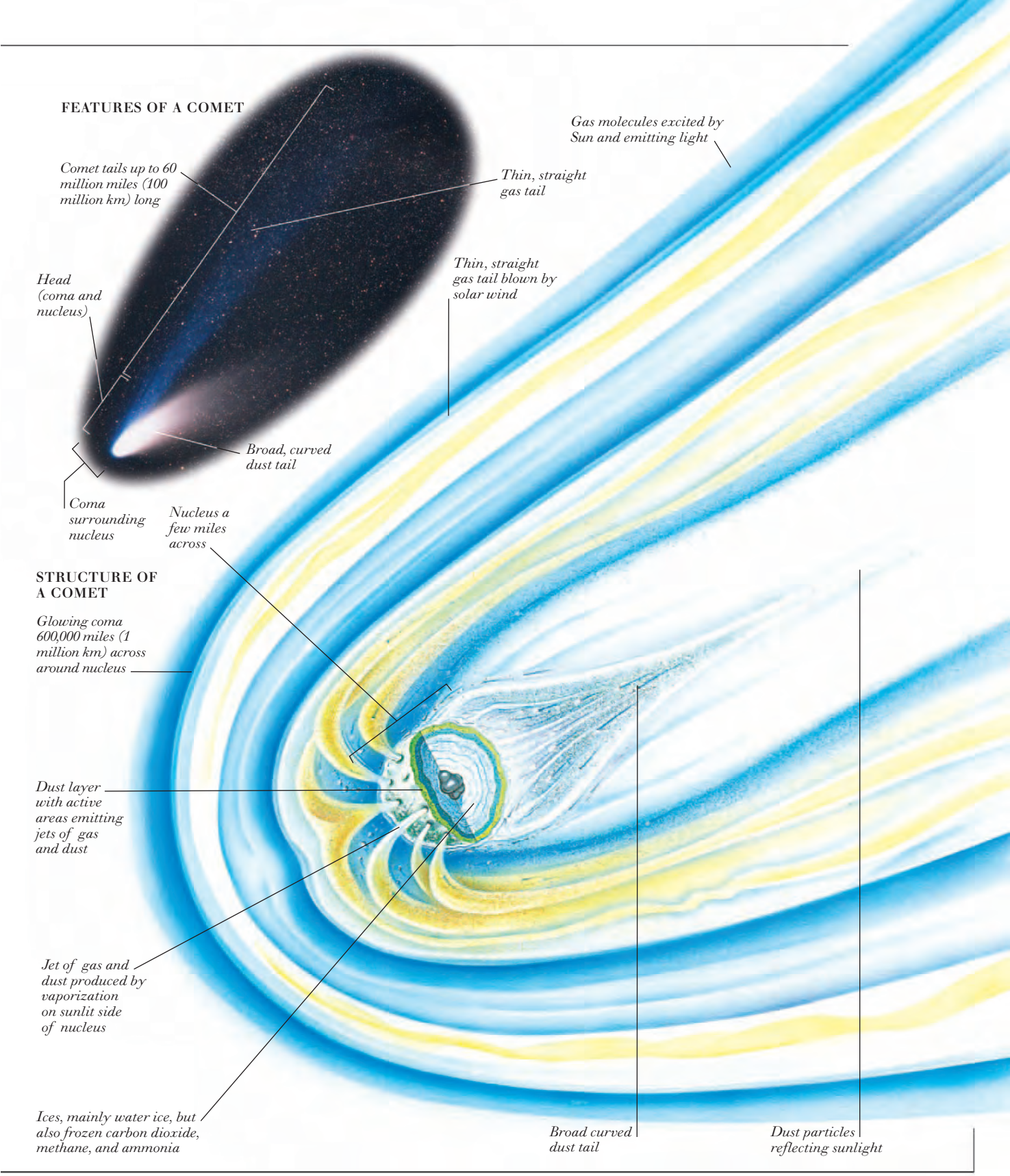
METEORITES

STONY METEORITE

STONY-IRON METEORITE

DEVELOPMENT OF COMET TAILS



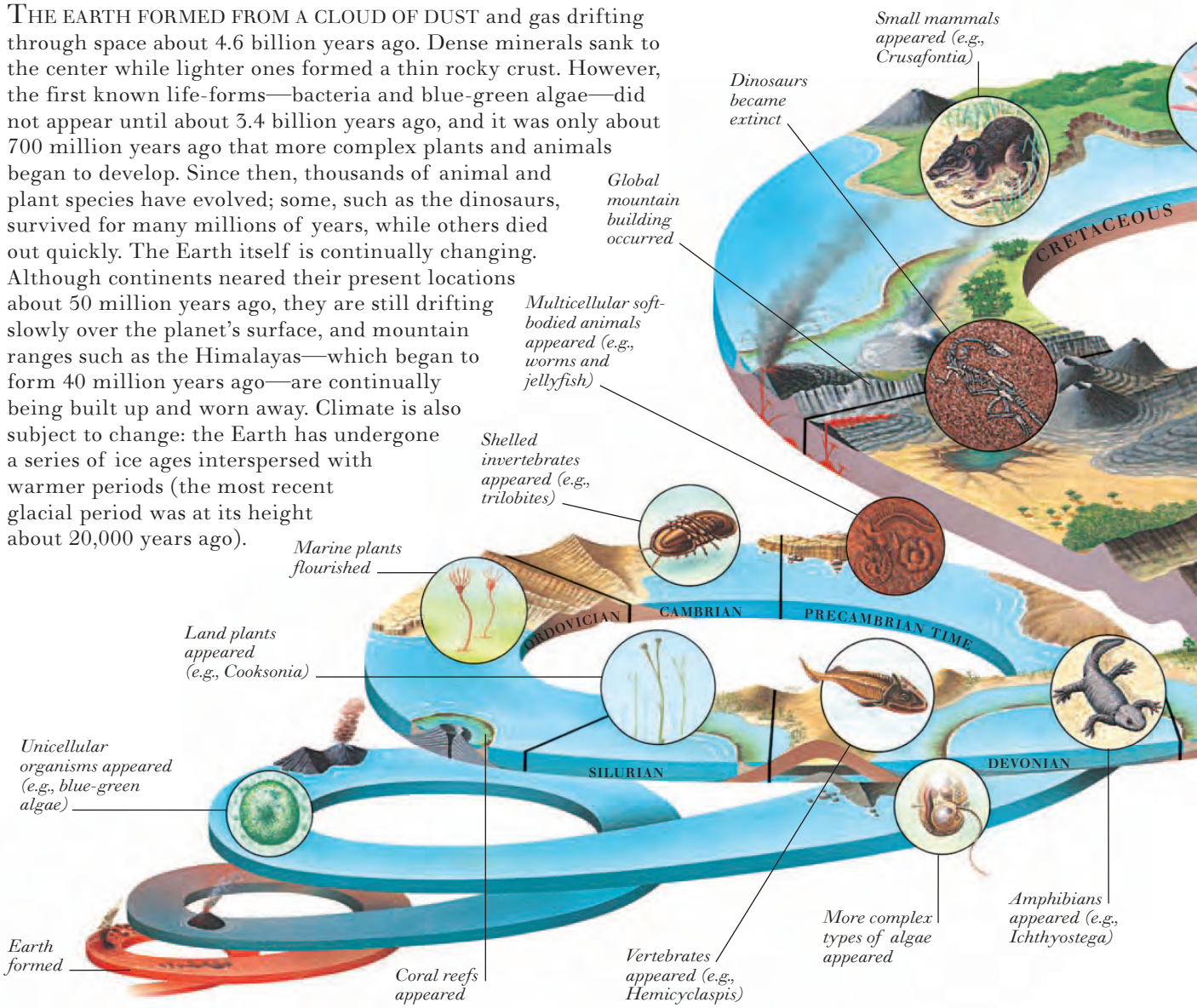

FEATURES OF A COMET
Comet tails up to 60 million miles (100 million km) long
Thin, straight gas tail
Gas molecules excited by Sun and emitting light
Thin, straight gas tail blown by solar wind
Head (coma and nucleus)
Broad, curved dust tail
Coma surrounding nucleus
Nucleus a few miles across
STRUCTURE OF A COMET
Glowing coma 600,000 miles (1 million km) across around nucleus
Dust layer with active areas emitting jets of gas and dust
Jet of gas and dust produced by vaporization on sunlit side of nucleus
Ices, mainly water ice, but also frozen carbon dioxide, methane, and ammonia
Broad curved dust tail
Dust particles reflecting sunlight

Prehistoric Earth

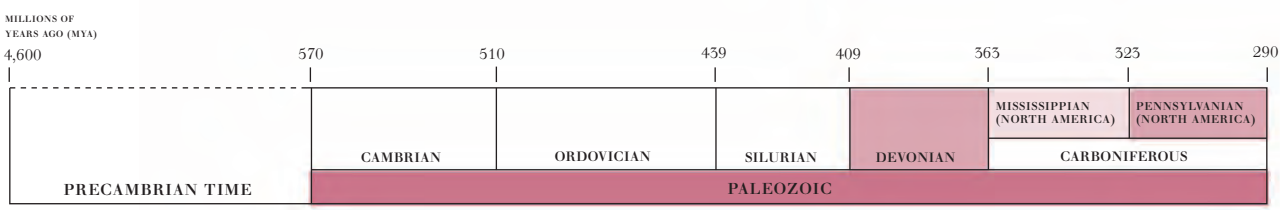
The Changing Earth 56
The Earth's Crust 58
Faults and Folds 60
Mountain Building 62
Precambrian to Devonian Period 64
Carboniferous to Permian Period 66
Triassic Period 68
Jurassic Period 70
Cretaceous Period 72
Tertiary Period 74
Quaternary Period 76
Early Signs of Life 78
Amphibians and Reptiles 80
The Dinosaurs 82
Theropods 1 84
Theropods 2 86
Sauropodomorphs 1 88
Sauropodomorphs 2 90
Thyreophorans 1 92
Thyreophorans 2 94
Ornithopods 1 96
Ornithopods 2 98
Marginocephalians 1 100
Marginocephalians 2 102
Mammals 1 104
Mammals 2 106
The First Humans 108

The changing Earth

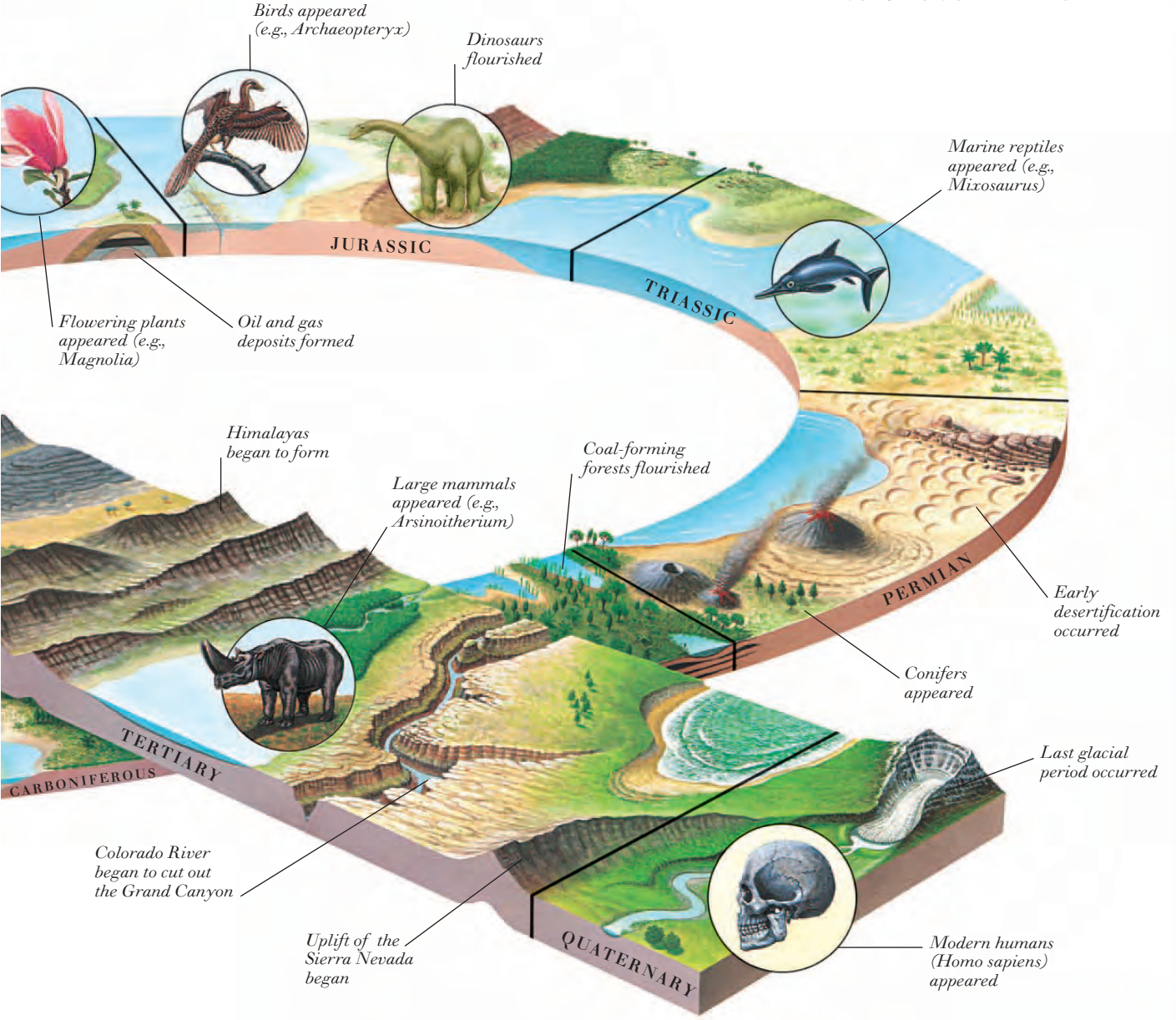
THE EARTH FORMED FROM A CLOUD OF DUST and gas drifting through space about 4.6 billion years ago. Dense minerals sank to the center while lighter ones formed a thin rocky crust. However, the first known life-forms—bacteria and blue-green algae—did not appear until about 3.4 billion years ago, and it was only about 700 million years ago that more complex plants and animals began to develop. Since then, thousands of animal and plant species have evolved; some, such as the dinosaurs, survived for many millions of years, while others died out quickly. The Earth itself is continually changing. Although continents neared their present locations about 50 million years ago, they are still drifting slowly over the planet's surface, and mountain ranges such as the Himalayas—which began to form 40 million years ago—are continually being built up and worn away. Climate is also subject to change: the Earth has undergone a series of ice ages interspersed with warmer periods (the most recent glacial period was at its height about 20,000 years ago).

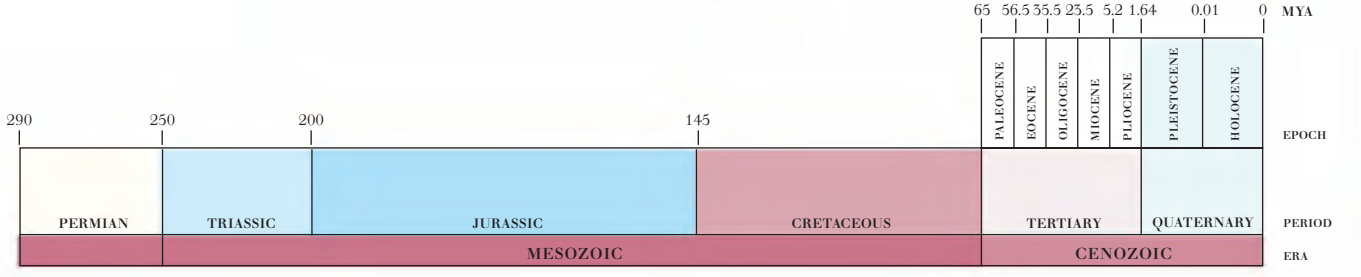


GEOLOGICAL TIMESCALE



EVOLUTION OF THE EARTH

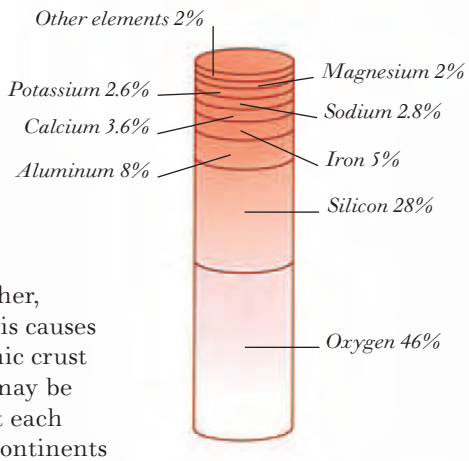




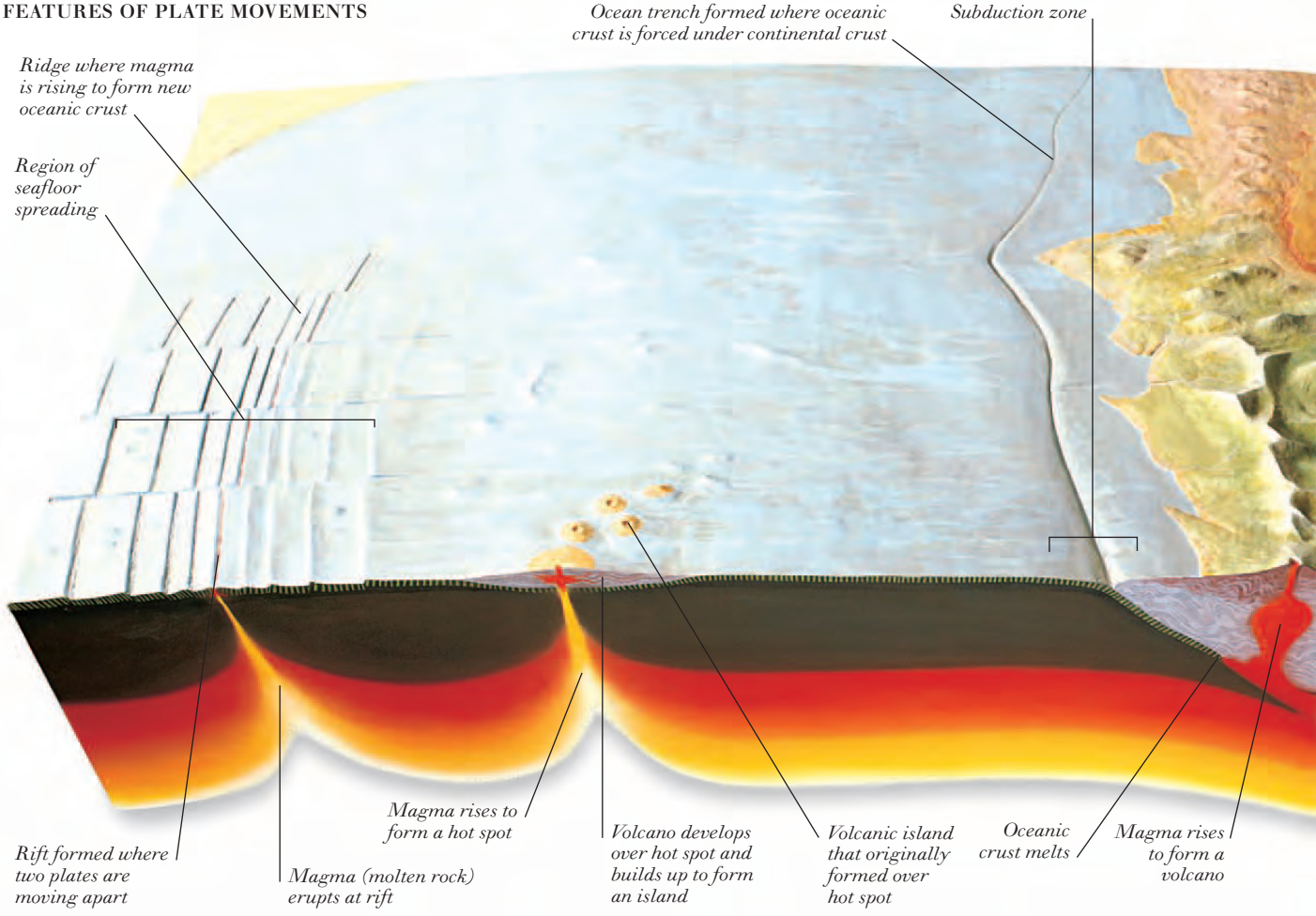
The Earth's crust

THE EARTH'S CRUST IS THE SOLID outer shell of the Earth. It includes continental crust (about 25 miles/40 km thick) and oceanic crust (about four miles/6 km thick). The crust and the topmost layer of the mantle form the lithosphere. The lithosphere consists of semirigid plates that move relative to each other on the underlying asthenosphere (a partly molten layer of the mantle). This process is known as plate tectonics and helps explain continental drift. Where two plates move apart, there are rifts in the crust. In mid-ocean, this movement results in seafloor spreading and the formation of ocean ridges; on continents, crustal spreading can form rift valleys. When plates move toward each other, one may be subducted beneath (forced under) the other. In mid-ocean, this causes ocean trenches, seismic activity, and arcs of volcanic islands. Where oceanic crust is subducted beneath continental crust or where continents collide, land may be uplifted and mountains formed (see pp. 62–65). Plates may also slide past each other—along the San Andreas fault, for example. Crustal movement on continents may result in earthquakes, while movement under the seabed can lead to tidal waves.

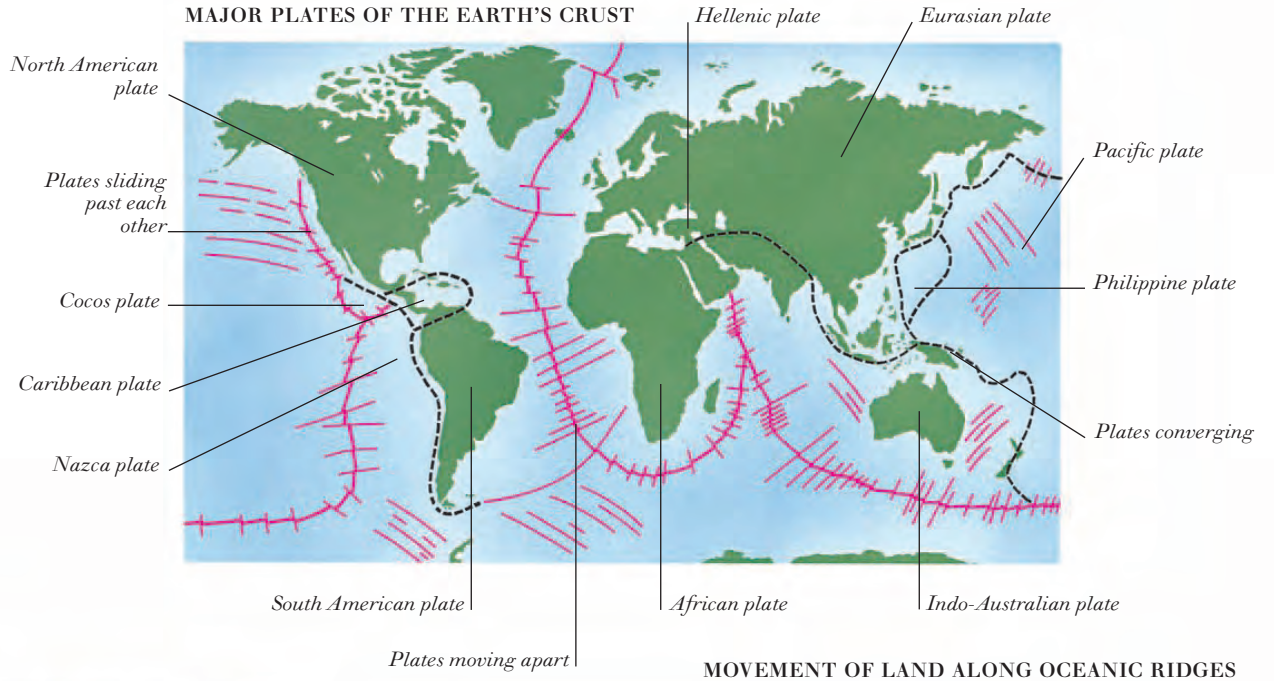
ELEMENTS IN THE EARTH'S CRUST

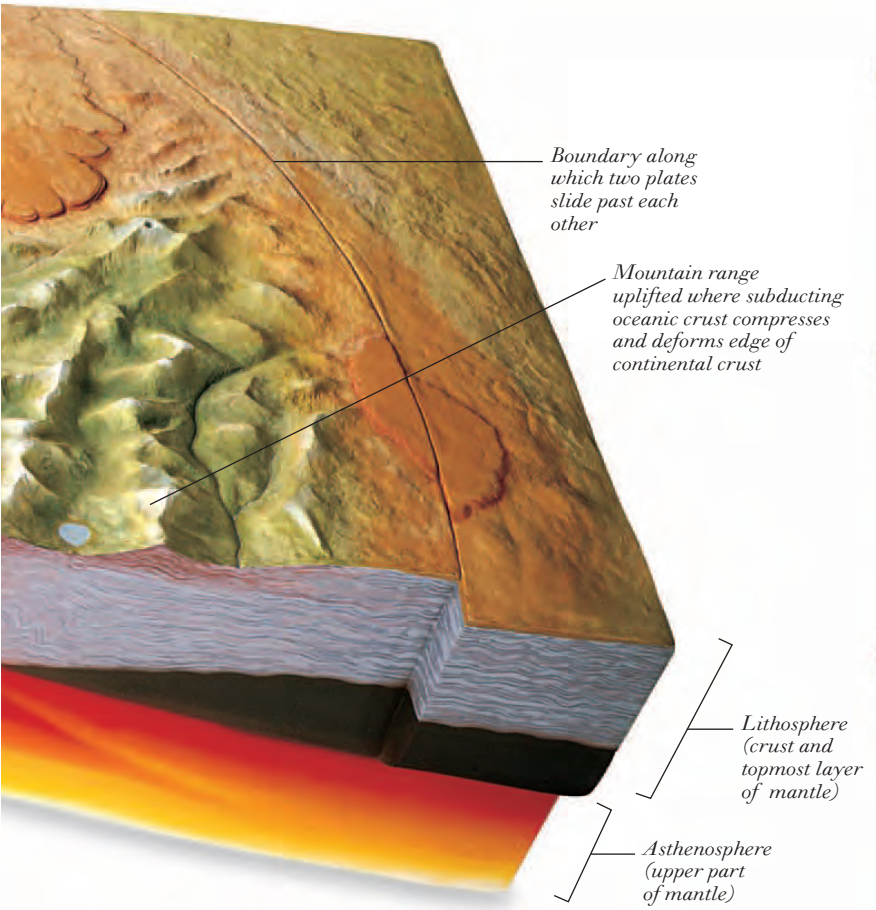


FEATURES OF PLATE MOVEMENTS

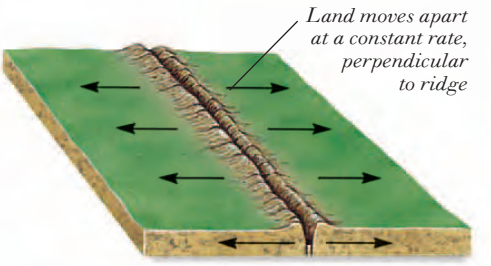


MAJOR PLATES OF THE EARTH'S CRUST

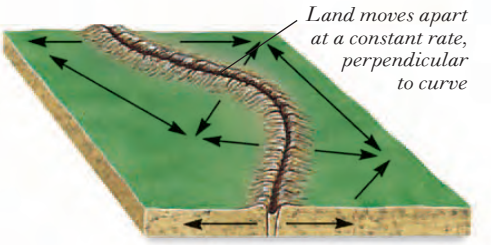




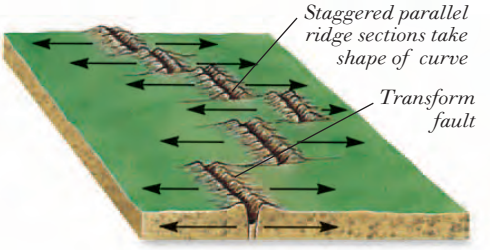
MOVEMENT OF LAND ALONG OCEANIC RIDGES



STRAIGHT OCEANIC RIDGE



CURVED OCEANIC RIDGE

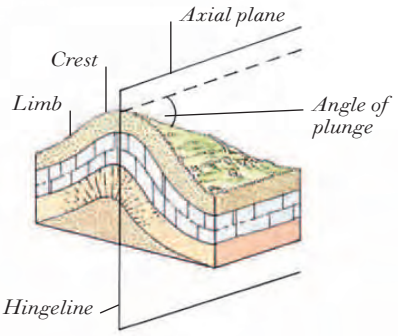


STRESSES RESOLVE INTO SECTIONS

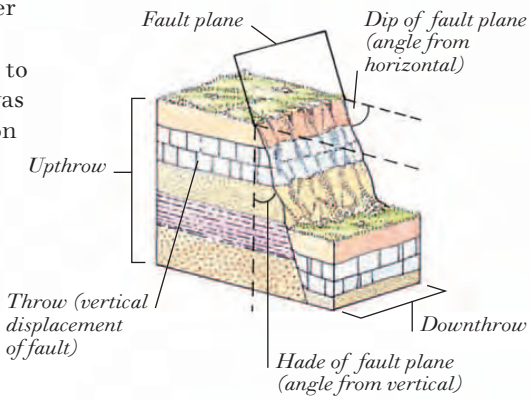
Faults and folds

THE CONTINUOUS MOVEMENT of the Earth's crustal plates (see pp. 58–59) can squeeze, stretch, or break rock strata, deforming them and producing faults and folds. A fault is a fracture in a rock along which there is movement of one side relative to the other. The movement can be vertical, horizontal, or oblique (vertical and horizontal). Faults develop when rocks are subjected to compression or tension. They tend to occur in hard, rigid rocks, which are more likely to break than bend. The smallest faults occur in single mineral crystals and are microscopically small, whereas the largest—the Great Rift Valley in Africa, which formed between 5 million and 100,000 years ago—is more than 6,000 miles (9,000 km) long. A fold is a bend in a rock layer caused by compression. Folds occur in elastic rocks, which tend to bend rather than break. The two main types of fold are anticlines (upfolds) and synclines (downfolds). Folds vary in size from a few millimeters long to folded mountain ranges hundreds of miles long, such as the Himalayas (see pp. 62–63) and the Alps, which are repeatedly folding. In addition to faults and folds, other features associated with rock deformations include boudins, mullions, and *en échelon* fractures.

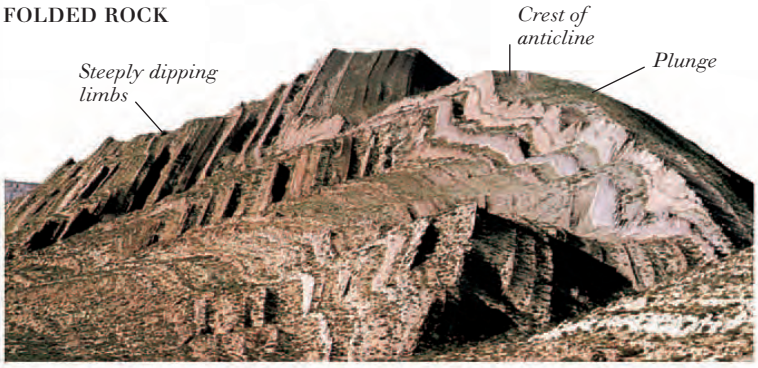
STRUCTURE OF A FOLD



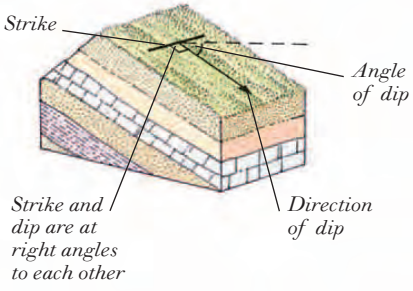
STRUCTURE OF A FAULT



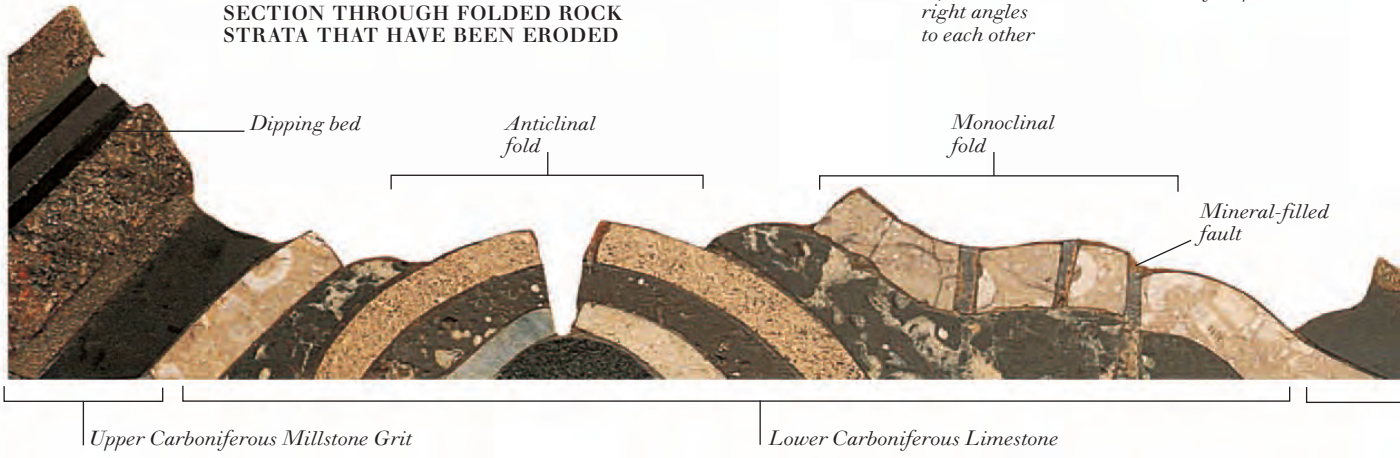
FOLDED ROCK



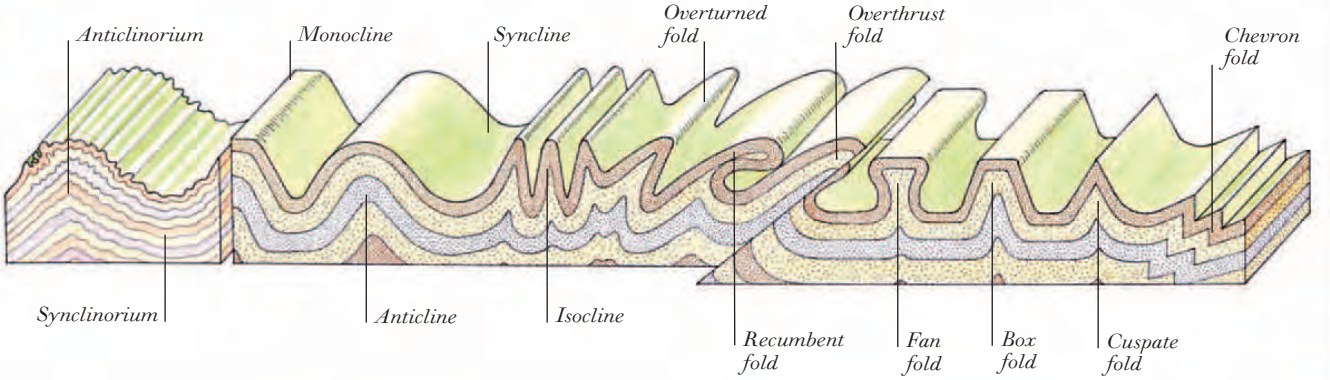
STRUCTURE OF A SLOPE



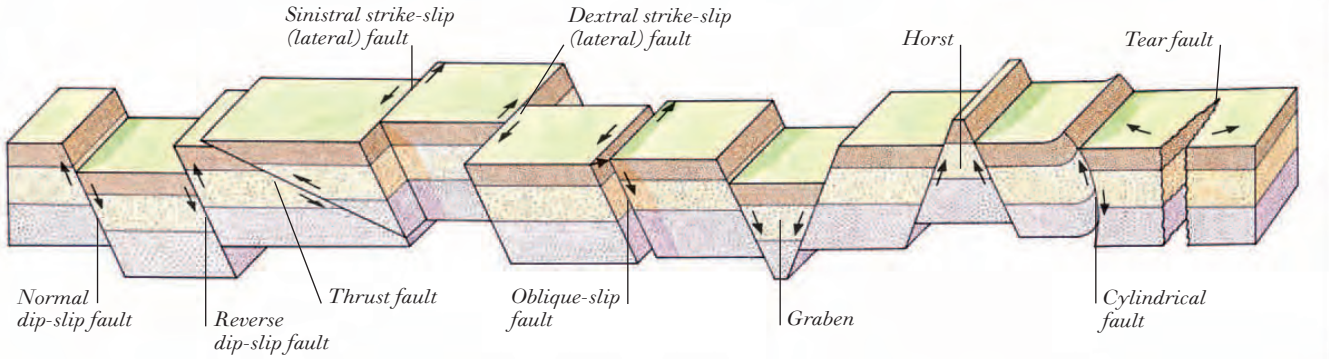
SECTION THROUGH FOLDED ROCK STRATA THAT HAVE BEEN ERODED



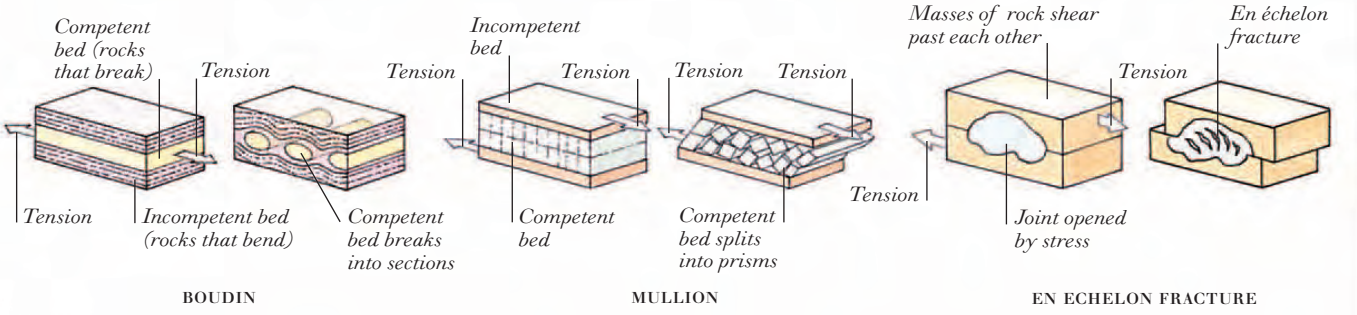
EXAMPLES OF FOLDS



EXAMPLES OF FAULTS



SMALL-SCALE ROCK DEFORMATIONS

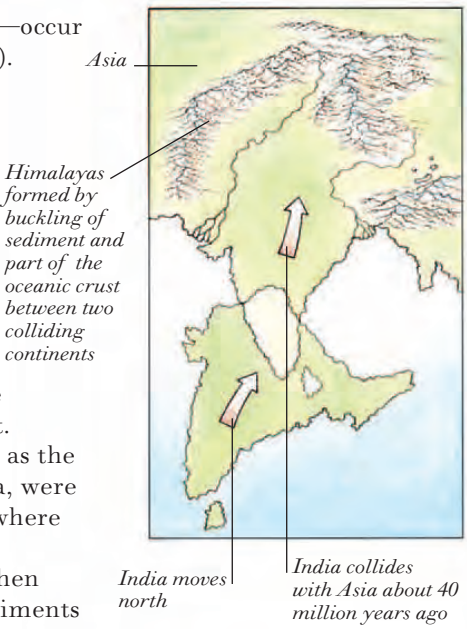


Mountain building

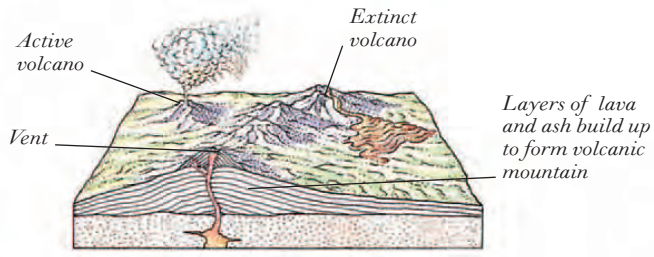
THE PROCESSES INVOLVED in mountain building—termed orogenesis—occur as a result of the movement of the Earth's crustal plates (see pp. 58–59). There are three main types of mountains: volcanic mountains, fold mountains, and block mountains. Most volcanic mountains have been formed along plate boundaries where plates have come together or moved apart and lava and other debris have been ejected onto the Earth's surface. The lava and debris may have built up to form a dome around the vent of a volcano. Fold mountains are formed where plates push together and cause the rock to buckle upward. Where oceanic crust meets less dense continental crust, the oceanic crust is forced under the continental crust. The continental crust is buckled by the impact. This is how folded mountain ranges, such as the Appalachian Mountains in North America, were formed. Fold mountains are also formed where two areas of continental crust meet. The Himalayas, for example, began to form when India collided with Asia, buckling the sediments and parts of the oceanic crust between them. Block mountains are formed when a block of land is uplifted between two faults as a result of compression or tension in the Earth's crust (see pp. 60–61). Often, the movement along faults has taken place gradually over millions of years. However, two plates may cause an earthquake by suddenly sliding past each other along a faultline.

BHAGIRATHI PARBAT, HIMALAYAS

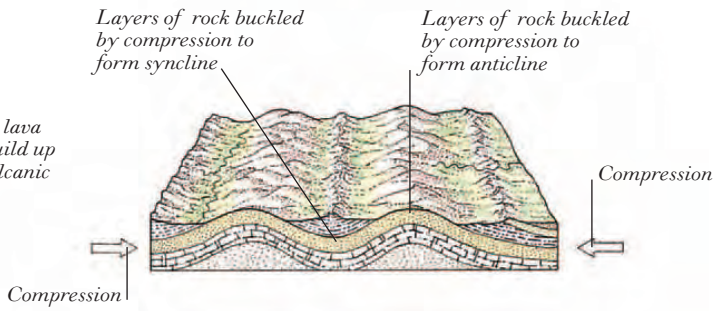
FORMATION OF THE HIMALAYAS



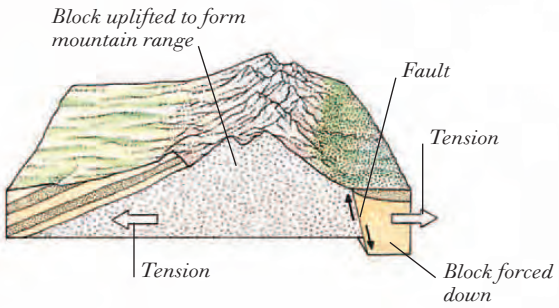
EXAMPLES OF MOUNTAINS



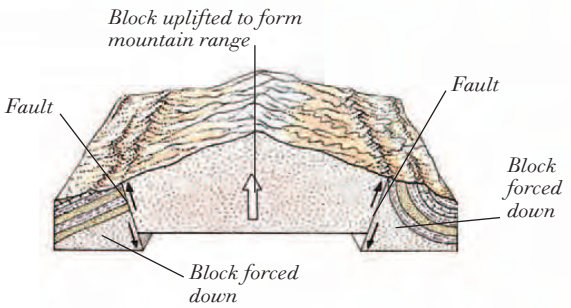
VOLCANIC MOUNTAIN



FOLD MOUNTAIN

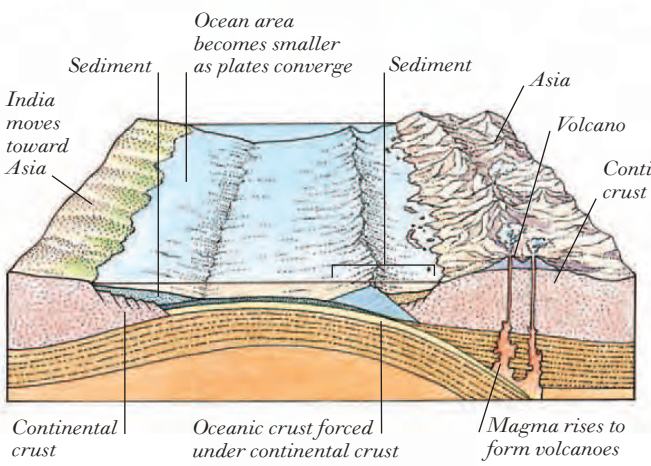


BLOCK-FAULT MOUNTAIN

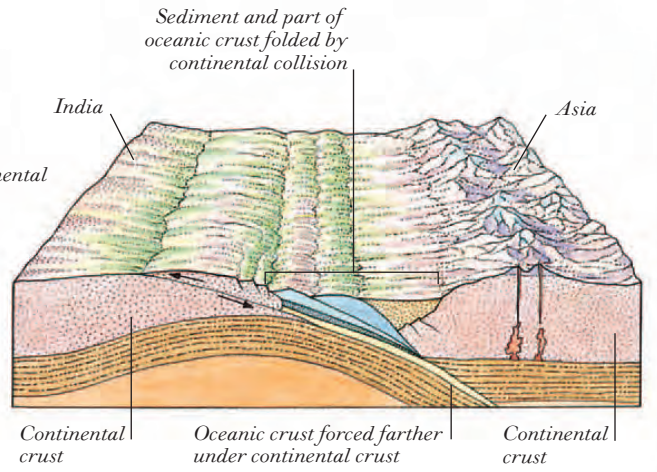


UPLIFTED BLOCK-FAULT MOUNTAIN

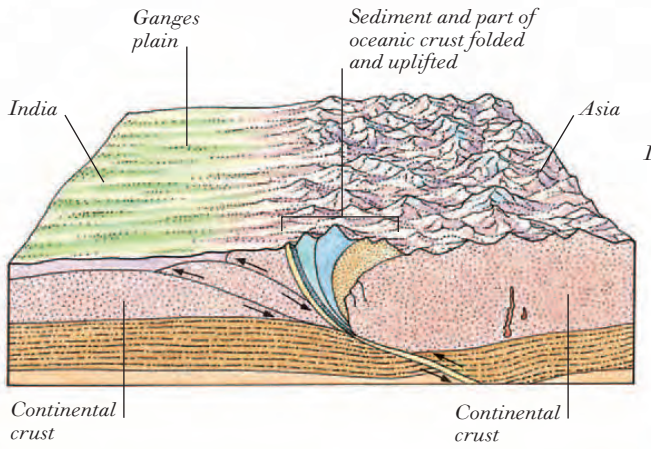
STAGES IN THE FORMATION OF THE HIMALAYAS



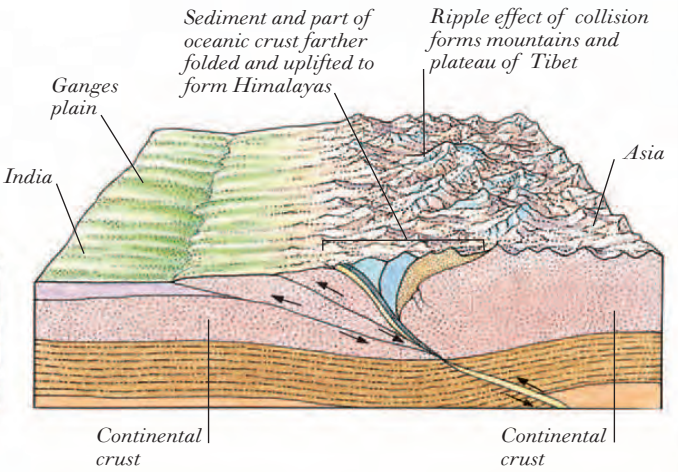
60 MILLION YEARS AGO



40 MILLION YEARS AGO



20 MILLION YEARS AGO

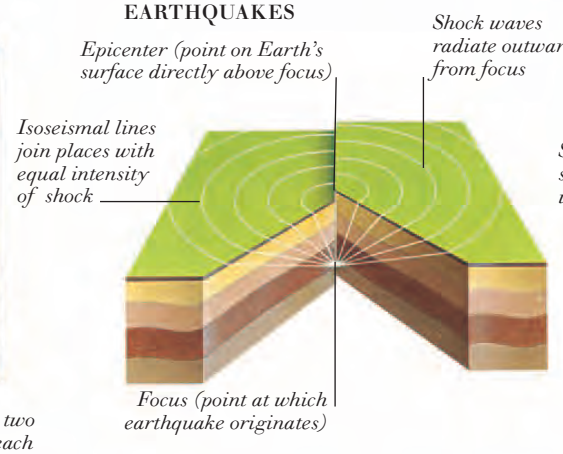


TODAY

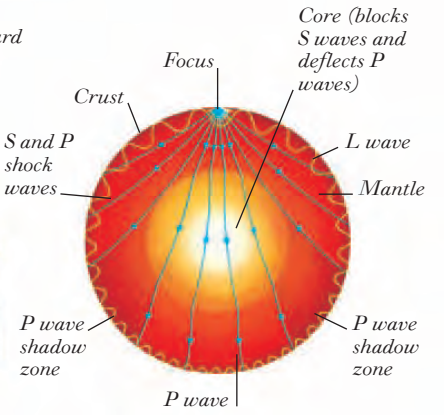
SAN ANDREAS FAULT

Faultline along which two plates may slide past each other, causing an earthquake

EARTHQUAKES



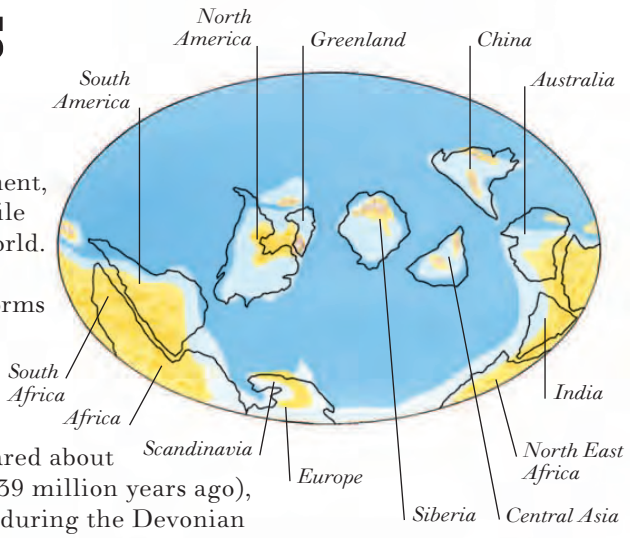
ANATOMY OF AN EARTHQUAKE



PATH OF SHOCK WAVES THROUGH THE EARTH

Precambrian to Devonian periods

MIDDLE ORDOVICIAN POSITIONS OF PRESENT-DAY LANDMASSES



WHEN THE EARTH FORMED about 4.6 billion years ago, its atmosphere consisted of volcanic gases with little oxygen, making it hostile to most forms of life. One large supercontinent, Gondwana, was situated over the southern polar region, while other smaller continents were spread over the rest of the world. Constant movement of the Earth's crustal plates carried continents across the earth's surface. The first primitive life-forms emerged around 3.4 billion years ago in shallow, warm seas. The build up of oxygen began to form a shield of ozone around the Earth, protecting living organisms from the Sun's harmful rays and helping to establish an atmosphere in which life could sustain itself. The first vertebrates appeared about 470 million years ago, during the Ordovician period (510–439 million years ago), the first land plants appeared around 400 million years ago during the Devonian period (409–363 million years ago), and the first land animals about 30 million years later.

EXAMPLES OF PRECAMBRIAN TO DEVONIAN PLANT GROUPS

A PRESENT-DAY CLUBMOSS
(Lycopodium sp.)

A PRESENT-DAY LAND PLANT
(Asparagus setaceous)

FOSSIL OF AN EXTINCT LAND PLANT
(Cooksonia hemisphaerica)

FOSSIL OF AN EXTINCT SWAMP PLANT
(Zosterophyllum llanoveranum)

EXAMPLES OF PRECAMBRIAN TO DEVONIAN TRILOBITES

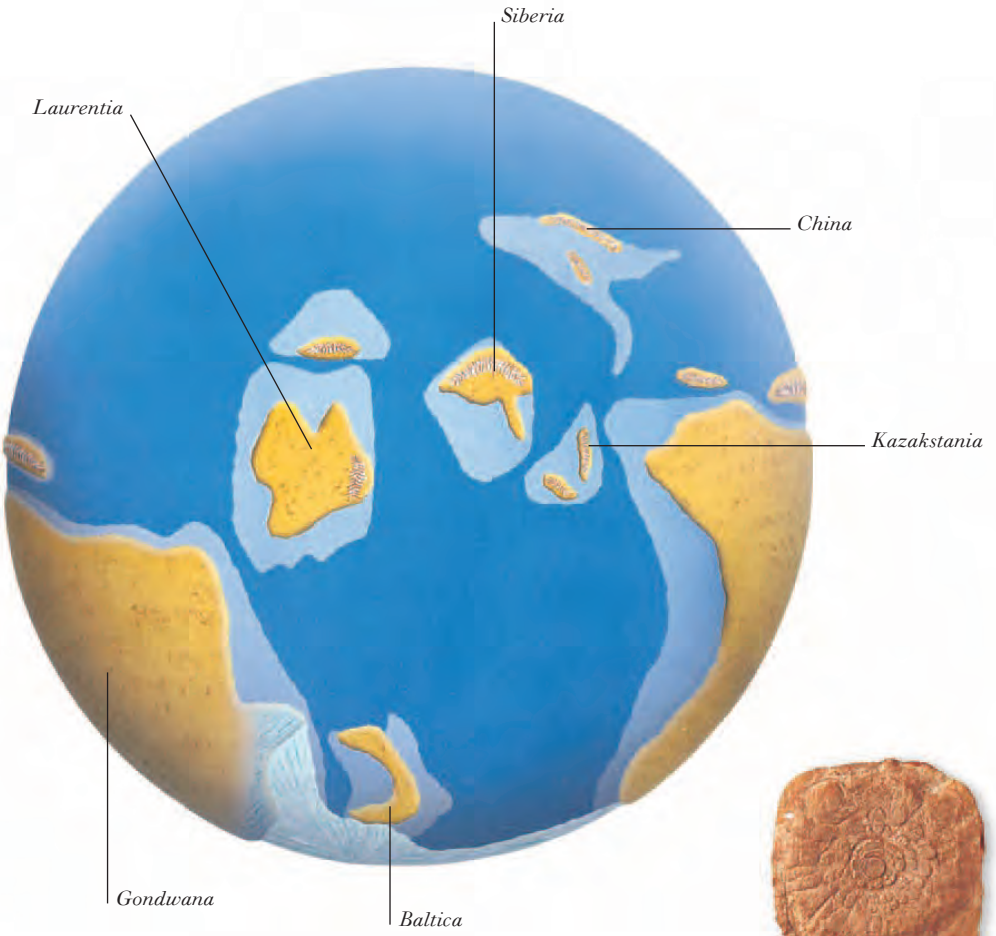
ACADAGNOSTUS
Group: Agnostidae
Length: ⅓ in (8 mm)

PHACOPS
Group: Phacopidae
Length: 1¾ in (4.5 cm)

OLENELLUS
Group: Olenellidae
Length: 2½ in (6 cm)

ELRATHIA
Group: Ptychopariidae
Length: ¾ in (2 cm)

THE EARTH DURING THE MIDDLE ORDOVICIAN PERIOD



EXAMPLES OF EARLY MARINE INVERTEBRATES

FOSSIL NAUTILOID
(Estonioceras perforatum)

FOSSIL BRACHIOPOD
(Dicoelosia bilobata)

TRACE FOSSIL
(Mawsonites spriggi)

FOSSIL GRAPTOLITE
(Monograptus convolutus)

EXAMPLES OF DEVONIAN FISH

RHAMPHODOPSIS
Group: Ptyctodontidae
Length: 6 in (15 cm)

PTERASPIS
Group: Pteraspidae
Length: 10 in (25 cm)

COCCOSTEUS
Group: Coccosteidae
Length: 14 in (35 cm)

BOTHRIOLEPIS
Group: Bothriolepididae
Length: 16 in (40 cm)

CHEIRACANTHUS
Group: Acanthodidae
Length: 12 in (30 cm)

PTERICHTHYODES
Group: Asterolepididae
Length: 6 in (15 cm)

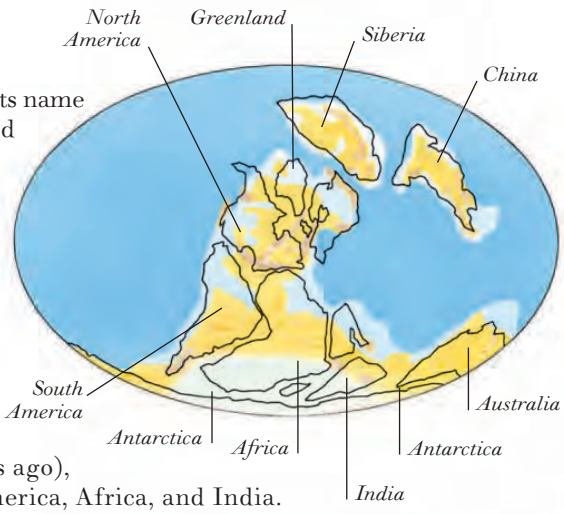
CHEIROLEPIS
Group: Cheirolepidae
Length: 6¾ in (17 cm)

CEPHALASPIS
Group: Cephalaspidae
Length: 8¾ in (22 cm)

Carboniferous to Permian periods

THE CARBONIFEROUS PERIOD (363–290 million years ago) takes its name from the thick, carbon-rich layers—now coal—that were produced during this period as swampy tropical forests were repeatedly drowned by shallow seas. The humid climate across northern and equatorial continents throughout Carboniferous times produced the first dense plant cover on Earth. During the early part of this period, the first reptiles appeared. Their development of a waterproof egg with a protective internal structure ended animal life's dependence on an aquatic environment. Toward the end of Carboniferous times, the earth's continents Laurasia and Gondwana collided, resulting in the huge landmass of Pangaea. Glaciers smothered much of the southern hemisphere during the Permian period (290–245 million years ago), covering Antarctica, parts of Australia, and much of South America, Africa, and India. Ice locked up much of the world's water and large areas of the northern hemisphere experienced a drop in sea level. Away from the poles, deserts and a hot dry climate predominated. As a result of these conditions, the Permian period ended with the greatest mass extinction of life on Earth ever.

LATE CARBONIFEROUS POSITIONS OF PRESENT-DAY LANDMASSES



EXAMPLES OF CARBONIFEROUS AND PERMIAN PLANT GROUPS

A PRESENT-DAY FIR
(Abies concolor)

FOSSIL OF AN EXTINCT FERN
(Zeilleria frenzlii)

FOSSIL OF AN EXTINCT HORSETAIL
(Equisetites sp.)

FOSSIL OF AN EXTINCT CLUBMOSS
(Lepidodendron sp.)

EXAMPLES OF CARBONIFEROUS AND PERMIAN TREES

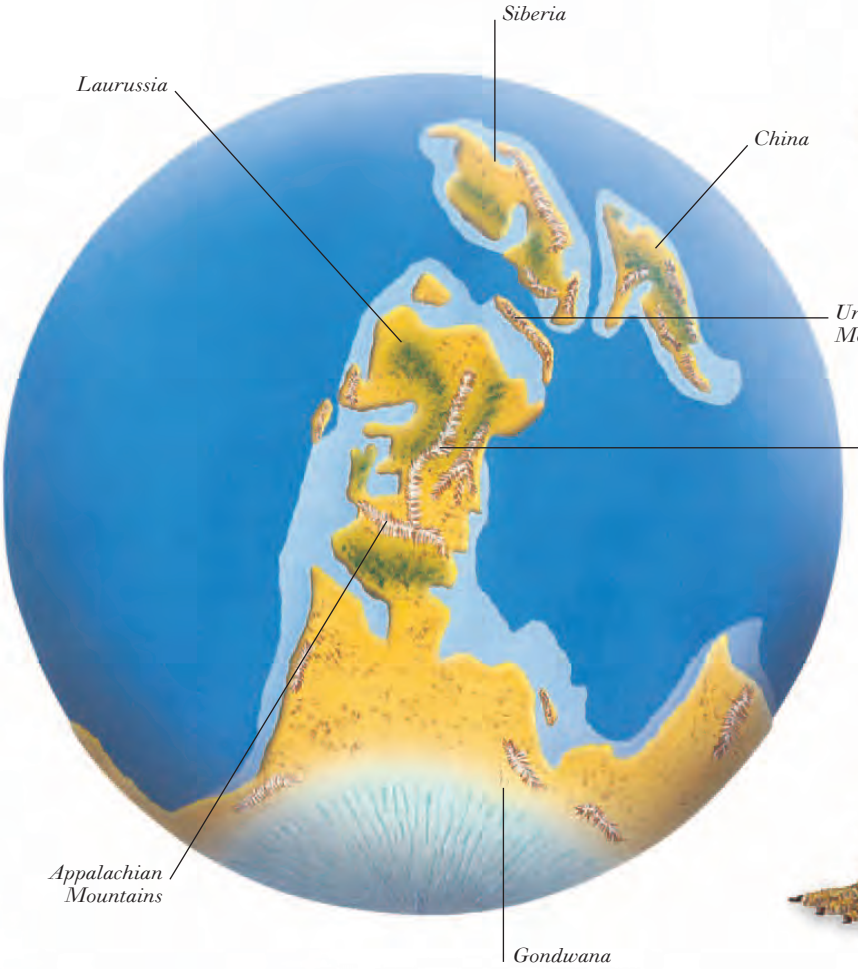
PECOPTERIS
Group: Marattiaceae
Height: 13 ft (4 m)

PARIPTERIS
Group: Medullosaceae
Height: 16 ft 6 in (5 m)

MARIOPTERIS
Group: Lyginopteridales
Height: 16 ft 6 in (5 m)

MEDULLOSA
Group: Medullosaceae
Height: 16 ft 6 in (5 m)

THE EARTH DURING THE LATE CARBONIFEROUS PERIOD



EXAMPLES OF CARBONIFEROUS AND PERMIAN ANIMALS

SKULL OF AN EXTINCT SYNAPSID
(Dimetrodon loomisi)

FOSSIL TEETH OF AN EXTINCT SHARK
(Helicoprion bessonowi)

MODEL OF AN EXTINCT EARLY REPTILELIKE ANIMAL
(Westlothiana lizziae)

LEPIDODENDRON
Group: Lepidodendraceae
Height: 100 ft (30 m)

CORDAITES
Group: Cordaitacea
Height: 33 ft (10 m)

GLOSSOPTERIS
Group: Glossopteridaceae
Height: 26 ft (8 m)

ALETHOPTERIS
Group: Medullosaceae
Height: 16 ft 6 in (5 m)

Triassic period

THE TRIASSIC PERIOD (250–200 million years ago) marked the beginning of what is known as the Age of the Dinosaurs (the Mesozoic era). During this period, the present-day continents were massed together, forming one huge continent known as Pangaea. This landmass experienced extremes of climate, with lush green areas around the coast or by lakes and rivers, and arid deserts in the interior. The only forms of plant life were nonflowering plants, such as conifers, ferns, cycads, and ginkgos; flowering plants had not yet evolved. The principal forms of animal life included diverse, often gigantic, amphibians, rhynchosaurs ("beaked lizards"), and primitive crocodilians. Dinosaurs first appeared about 230 million years ago, at the beginning of the Late Triassic period. Among the earliest dinosaurs were the carnivorous (flesh-eating) herrerasaurids, such as *Herrerasaurus* and *Staurikosaurus*. Early herbivorous (plant-eating) dinosaurs first appeared in Late Triassic times and included *Plateosaurus* and *Technosaurus*. By the end of the Triassic period, dinosaurs dominated Pangaea, possibly contributing to the extinction of many other reptiles.

TRIASSIC POSITIONS OF PRESENT-DAY LANDMASSES

EXAMPLES OF TRIASSIC PLANT GROUPS

A PRESENT-DAY CYCAD
(Cycas revoluta)

A PRESENT-DAY GINKGO
(Ginkgo biloba)

A PRESENT-DAY CONIFER
(Araucaria araucana)

FOSSIL OF AN EXTINCT FERN
(Pachypteris sp.)

FOSSIL LEAF OF AN EXTINCT CYCAD
(Cycas sp.)

EXAMPLES OF TRIASSIC DINOSAURS

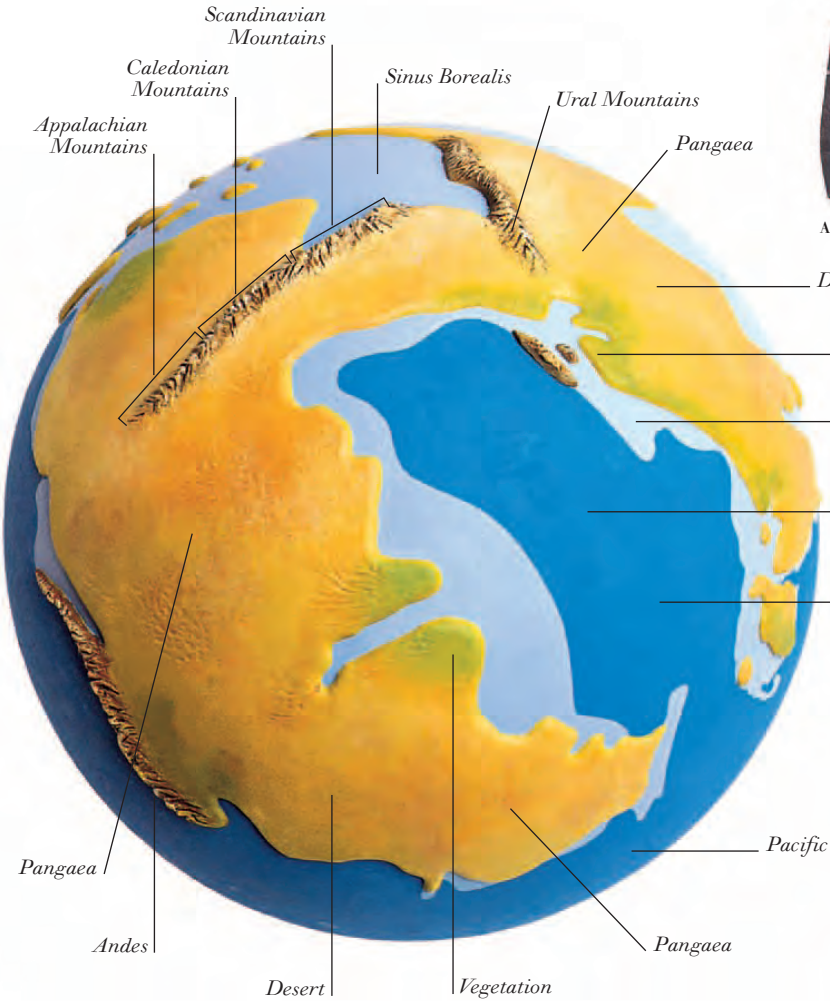
MELANOROSAURUS
Group: Melanorosauridae
Length: 40 ft (12.2 m)

MUSSAURUS
Group: Sauropodomorpha
Length: 6 ft 6 in–10 ft (2–3 m)

HERRERASAURUS
Group: Herrerasauridae
Length: 10 ft (3 m)

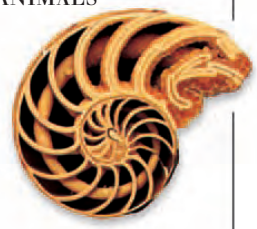
PISANOSAURUS
Group: Ornithischia
Length: 3 ft (90 cm)

THE EARTH DURING THE TRIASSIC PERIOD



EXAMPLES OF TRIASSIC ANIMALS

AN EXTINCT AMPHIBIAN



A NAUTILOID MOLLUSK
(Nautilus sp.)

AN EXTINCT CHONDROSTEAN FISH
(Cleithrolepis granulatus)

AN EXTINCT SEA-GOING REPTILE
(Pachypleurosaurus sp.)

AN EXTINCT RHYNCHOSAURIAN REPTILE
(Scaphonyx fischeri)

PLATEOSAURUS
Group: Plateosauridae
Length: 26 ft (7.9 m)

TECHNOSAURUS
Group: Ornithischia
Length: 3 ft 3 in (1 m)

COELOPHYSIS
Group: Coelophysidae
Length: 10 ft (3 m)

STAURIKOSAURUS
Group: Herrerasauridae
Length: 6 ft 6 in (2 m)

Jurassic period

THE JURASSIC PERIOD, the middle part of the Mesozoic era, lasted from 199 to 145 million years ago. During Jurassic times, the landmass of Pangaea broke up into the continents of Gondwana and Laurasia, and sea levels rose, flooding areas of lower land. The Jurassic climate was warm and moist. Plants such as ginkgos, horsetails, and conifers thrived, and giant redwood trees appeared, as did the first flowering plants. The abundance of plant food coincided with the proliferation of herbivorous (plant-eating) dinosaurs, such as the large sauropods (e.g., *Diplodocus*) and stegosaurs (e.g., *Stegosaurus*). Carnivorous (flesheating) dinosaurs, such as *Compsognathus* and *Allosaurus*, also flourished by hunting the many animals that existed—among them other dinosaurs. Further Jurassic animals included shrewlike mammals, and pterosaurs (flying reptiles), as well as plesiosaurs and ichthyosaurs (both marine reptiles).

JURASSIC POSITIONS OF PRESENT-DAY LANDMASSES

EXAMPLES OF JURASSIC PLANT GROUPS

A PRESENT-DAY FERN
(Dicksonia antarctica)

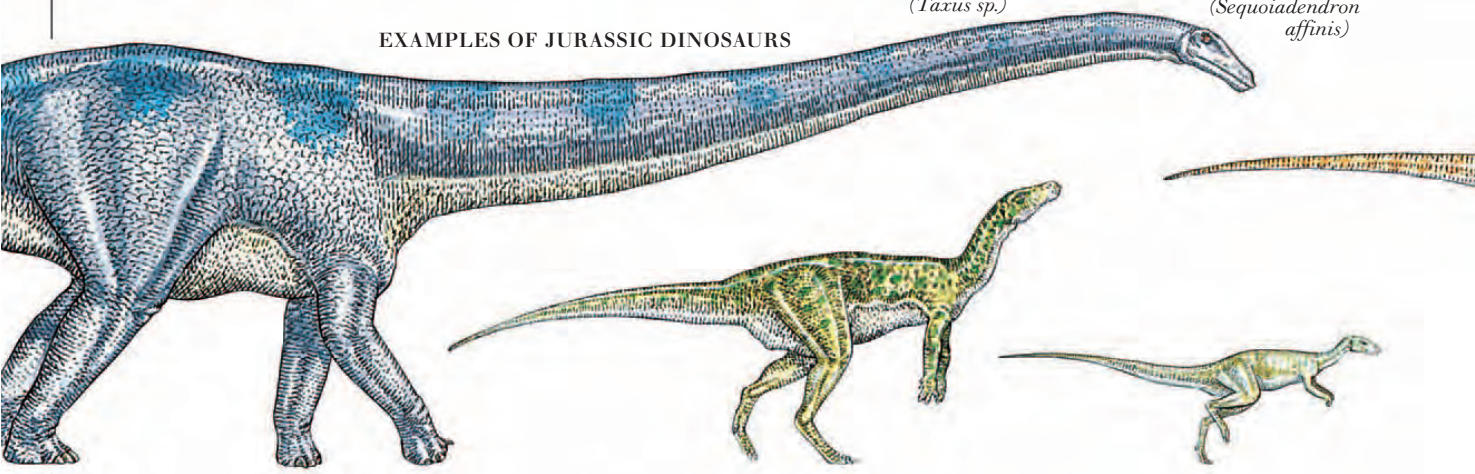
A PRESENT-DAY HORSETAIL
(Equisetum arvense)

A PRESENT-DAY CONIFER
(Taxus baccata)

FOSSIL LEAF OF AN EXTINCT CONIFER
(Taxus sp.)

FOSSIL LEAF OF AN EXTINCT REDWOOD
(Sequoiadendron affinis)

EXAMPLES OF JURASSIC DINOSAURS

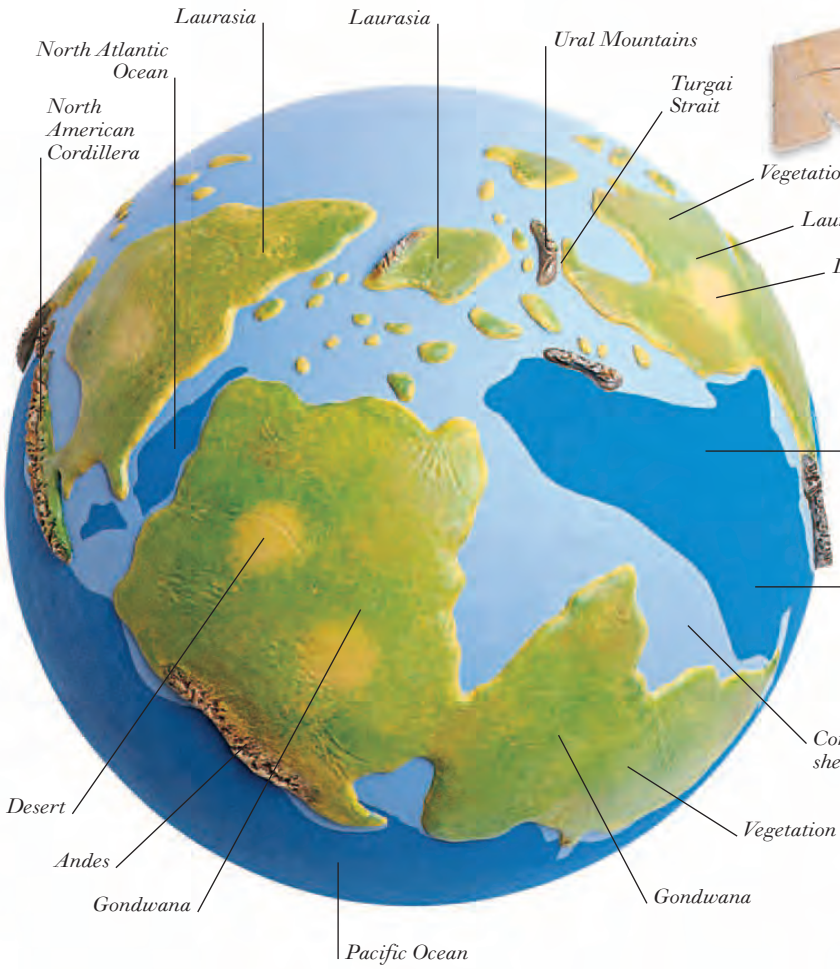


DIPLODOCUS
Group: Diplodocidae
Length: 88 ft (26.8 m)

CAMPTOSAURUS
Group: Iguanodontia
Length: 16–23 ft (4.9–7 m)

DRYOSAURUS
Group: Dryosauridae
Length: 10–13 ft (3–4 m)

THE EARTH DURING THE JURASSIC PERIOD



EXAMPLES OF JURASSIC ANIMALS

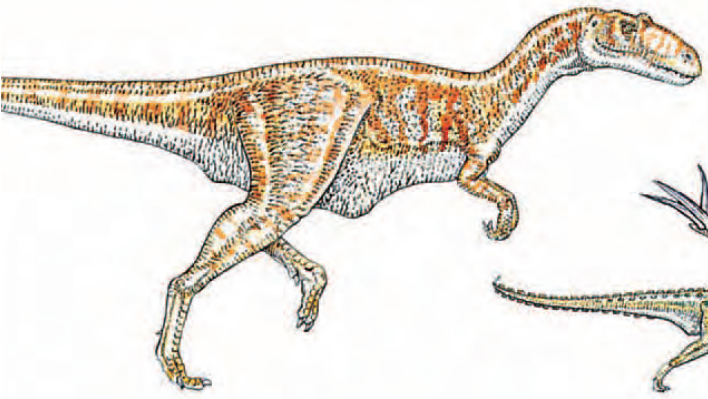
AN EXTINCT PTEROSAUR
(Rhamphorhynchus sp.)

AN EXTINCT BELEMNITE MOLLUSK
(Belemnoteuthis sp.)

AN EXTINCT RHYNCHOSAURIAN REPTILE
(Homeosaurus pulchellus)

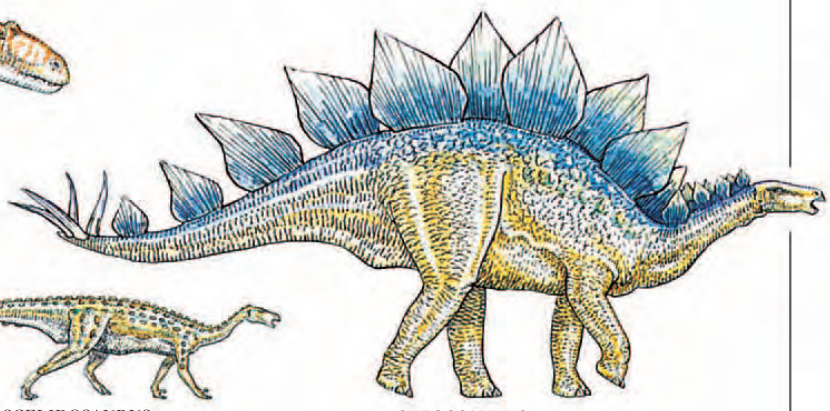
AN EXTINCT PLESIOSAUR
(Peloneustes philarcus)

AN EXTINCT ICHTHYOSAUR
(Stenopterygius megacephalus)



ALLOSAURUS
Group: Allosauroidea
Length: 36 ft (11 m)

SCELIDOSAURUS
Group: Thyreophora
Length: 13 ft (4m)



STEGOSAURUS
Group: Stegosauridae
Length: 30 ft (9.1 m)

Cretaceous period

THE MESOZOIC ERA ENDED WITH the Cretaceous period, which lasted from 146 to 65 million years ago. During this period, Gondwana and Laurasia were breaking up into smaller landmasses that more closely resembled the modern continents. The climate remained mild and moist but the seasons became more marked. Flowering plants, including deciduous trees, replaced many cycads, seed ferns, and conifers. Animal species became more varied, with the evolution of new mammals, insects, fish, crustaceans, and turtles. Dinosaurs evolved into a wide variety of species during Cretaceous times; more than half of all known dinosaurs—including *Iguanodon*, *Deinonychus*, *Tyrannosaurus*, and *Hypsilophodon*—lived during this period. At the end of the Cretaceous period, however, most dinosaurs became extinct. The reason for this mass extinction is unknown but it is thought to have been caused by climatic changes due to either a catastrophic meteor impact with the Earth or extensive volcanic eruptions.

CRETACEOUS POSITIONS OF PRESENT-DAY LANDMASSES

EXAMPLES OF CRETACEOUS PLANT GROUPS

A PRESENT-DAY CONIFER
(Pinus muricata)

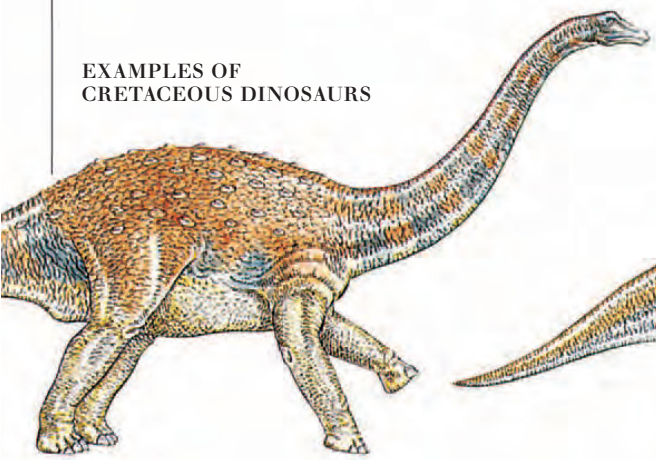
A PRESENT-DAY DECIDUOUS TREE
(Magnolia sp.)

FOSSIL OF AN EXTINCT FERN
(Sphenopteris latiloba)

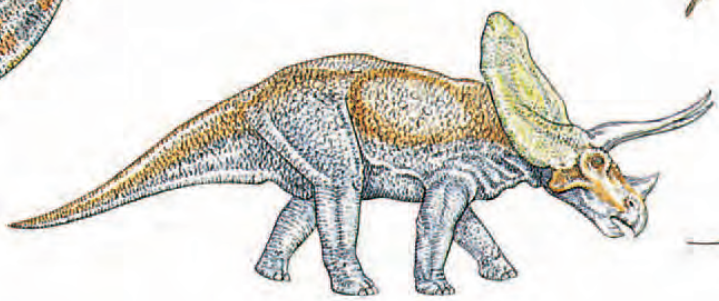
FOSSIL OF AN EXTINCT GINKGO
(Ginkgo pluripartita)

FOSSIL LEAVES OF AN EXTINCT DECIDUOUS TREE
(Cercidyphyllum sp.)

EXAMPLES OF CRETACEOUS DINOSAURS



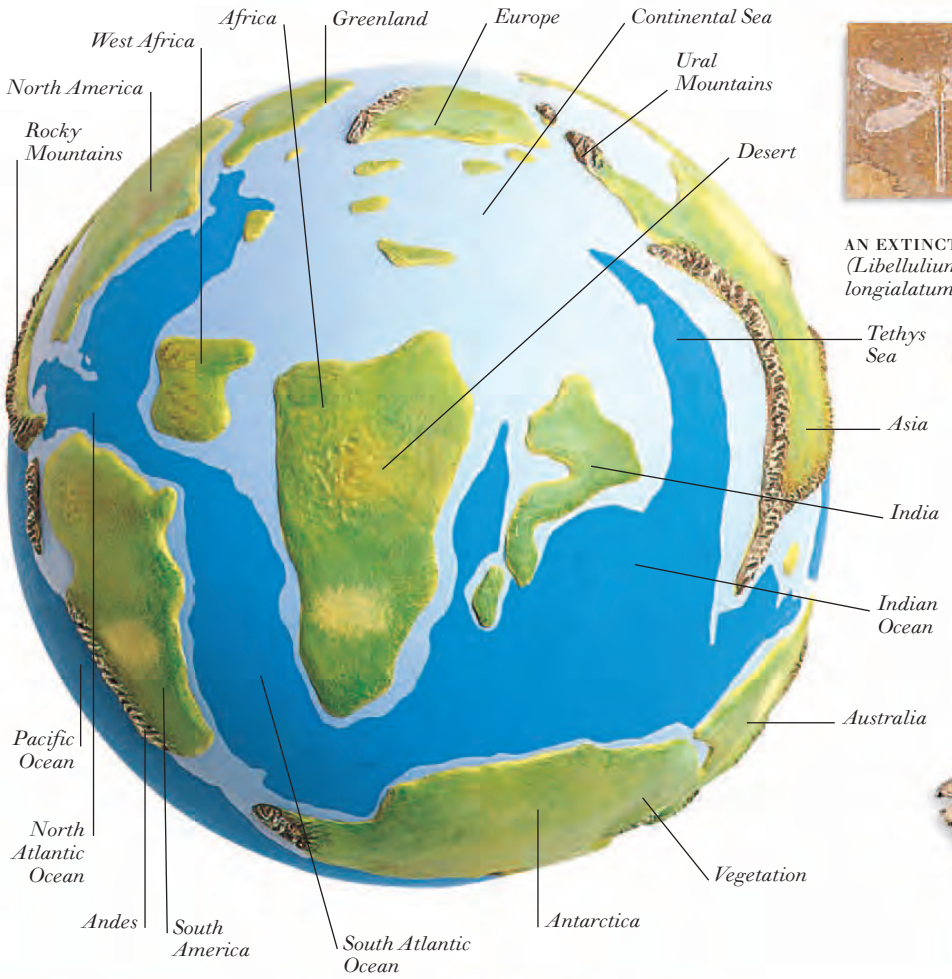
SALTASAURUS
Group: Saltasauridae
Length: 40 ft (12.2 m)



TOROSAURUS
Group: Ceratopsidae
Length: 25 ft (7.6 m)

HYPSILOPHODON
Group: Ornithopoda
Length: 4 ft 6 in–7 ft 6 in (1.4–2.3 m)

THE EARTH DURING THE CRETACEOUS PERIOD



EXAMPLES OF CRETACEOUS ANIMALS

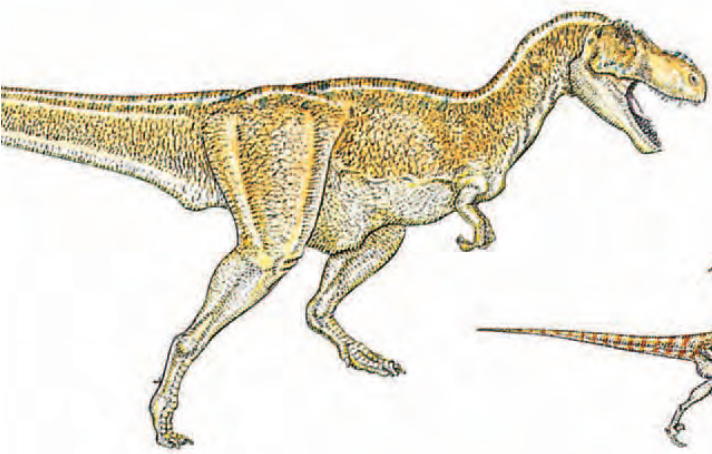
AN EXTINCT INSECT
(Libellulium longialatum)

AN EXTINCT MARINE TURTLE
(Plesiochelys latiscutata)

AN EXTINCT CRUSTACEAN
(Homarus sp.)

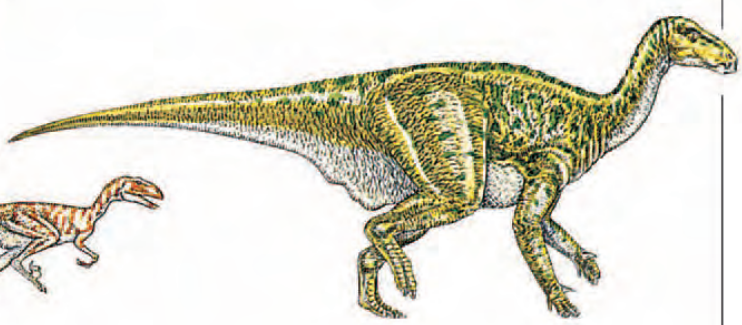
AN EXTINCT CROCODILIAN

AN EXTINCT HOLOSTEAN FISH
(Lepidotes maximus)



TYRANNOSAURUS
Group: Tyrannosauridae
Length: 40 ft (12.2 m)

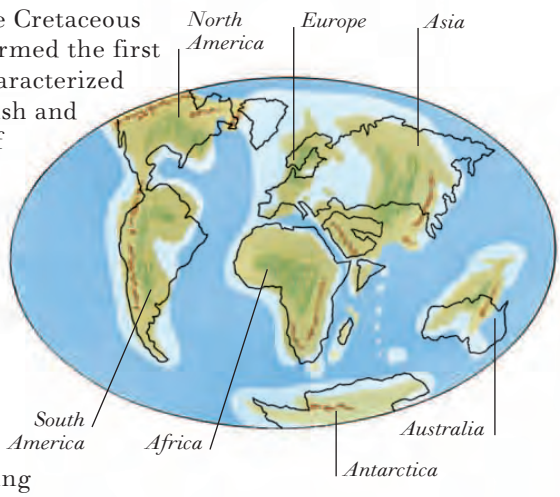
DEINONYCHUS
Group: Dromaeosauridae
Length: 8–11 ft (2.4–3.4 m)



IGUANODON
Group: Iguanodontia
Length: 30 ft (9.1 m)

Tertiary period

TERTIARY POSITIONS OF PRESENT-DAY LANDMASSES



FOLLOWING THE DEMISE OF THE DINOSAURS at the end of the Cretaceous period, the Tertiary period (65–1.6 million years ago), which formed the first part of the Cenozoic era (65 million years ago–present), was characterized by a huge expansion of mammal life. Placental mammals nourish and maintain the young in the mother's uterus; only a few groups of placental mammals existed during Cretaceous times, compared with a few dozen during the Tertiary period. One of these included the first hominid (see pp.108–109), *Ardipithecus*, which appeared in Africa. By the beginning of the Tertiary period, the continents had almost reached their present position. The Tethys Sea, which had separated the northern continents from Africa and India, began to close up, forming the Mediterranean Sea and allowing the migration of terrestrial animals between Africa and western Europe. India's collision with Asia led to the formation of the Himalayas. During the middle part of the Tertiary period, the forest-dwelling and browsing mammals were replaced by mammals such as the horses, better suited to grazing the open savannahs that began to dominate. Repeated cool periods throughout the Tertiary period established the Antarctic as an icy island continent.

EXAMPLES OF TERTIARY PLANT GROUPS

A PRESENT-DAY OAK
(Quercus palustris)

A PRESENT-DAY BIRCH
(Betula grossa)

FOSSIL LEAF OF AN EXTINCT BIRCH
(Betulites sp.)

FOSSILIZED STEM OF AN EXTINCT PALM
(Palmoxylon sp.)

EXAMPLES OF TERTIARY ANIMAL GROUPS

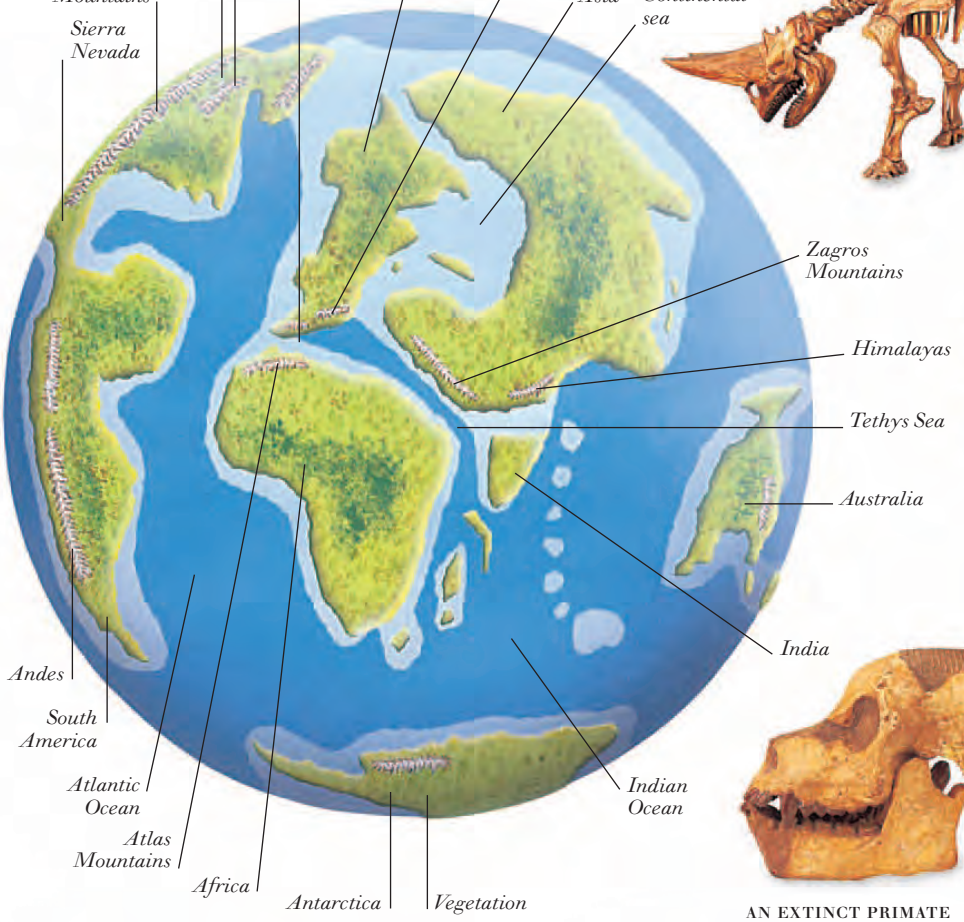
HYAENODON
Group: Hyaenodontidae
Length: 6 ft 6 in (2 m)

TITANOHYRAX
Group: Pliohyracidae
Length: 6 ft 6 in (2 m)

PHORUSRHACOS
Group: Phorusrhacidae
Length: 5 ft (1.5 m)

SAMOTHERIUM
Group: Giraffidae
Length: 10 ft (3 m)

THE EARTH DURING THE TERTIARY PERIOD



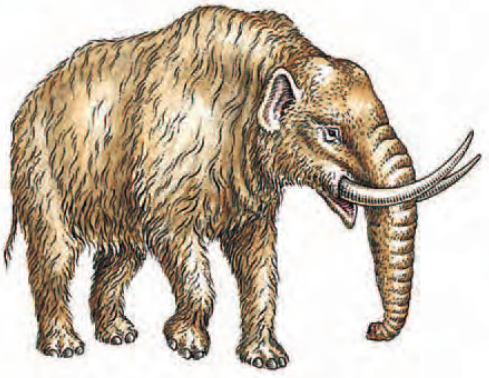
EXAMPLES OF TERTIARY ANIMALS

AN EXTINCT MAMMAL
(Arsinoitherium)

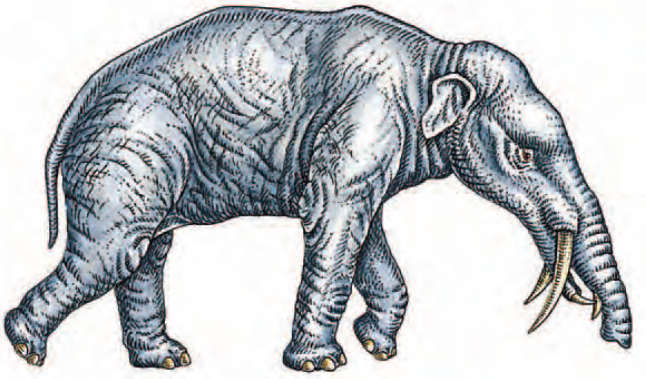
AN EXTINCT MAMMAL
(Merycoidodon culbertsonii)

AN EXTINCT PRIMATE
(Aegyptopithecus sp.)

AN EXTINCT GASTROPOD MOLLUSK
(Ecphora quadricostata)



MAMMUT
Group: Mammutidae
Length: 8 ft (2.5 m)

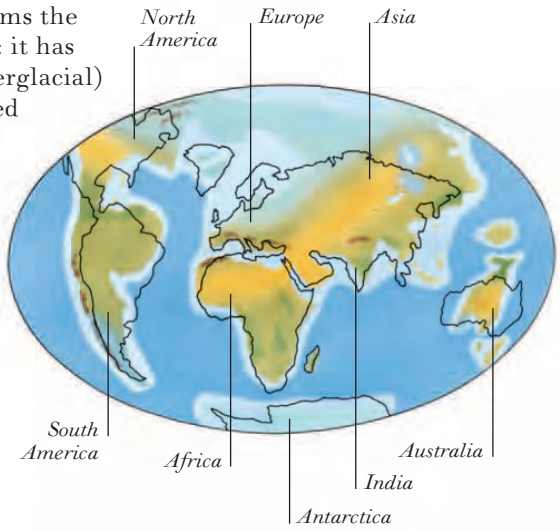


TETRALOPHODON
Group: Gomphotheriidae
Length: 8 ft (2.5 m)

Quaternary period

THE QUATERNARY PERIOD (1.6 million years ago–present) forms the second part of the Cenozoic era (65 million years ago–present): it has been characterized by alternating cold (glacial) and warm (interglacial) periods. During cold periods, ice sheets and glaciers have formed repeatedly on northern and southern continents. The cold environments in North America and Eurasia, and to a lesser extent in southern South America and parts of Australia, have caused the migration of many life-forms toward the Equator. Only the specialized ice age mammals such as *Mammuthus* and *Coelodonta*, with their thick wool and fat insulation, were suited to life in very cold climates. Humans developed throughout the Pleistocene period (1.6 million–10,000 years ago) in Africa and migrated northward into Europe and Asia. Modern humans, *Homo sapiens*, lived on the cold European continent 30,000 years ago and hunted other mammals. The end of the last ice age and the climatic changes that occurred about 10,000 years ago brought extinction to many Pleistocene mammals, but enabled humans to flourish.

QUATERNARY POSITIONS OF PRESENT-DAY LANDMASSES



EXAMPLES OF QUATERNARY PLANT GROUPS

A PRESENT-DAY BIRCH
(Betula lenta)

A PRESENT-DAY SWEEETGUM
(Liquidambar styraciflua)

FOSSIL LEAF OF A SWEETGUM
(Liquidambar europeanum)

FOSSIL LEAF OF A BIRCH
(Betula sp.)

EXAMPLES OF QUATERNARY ANIMAL GROUPS

PROCOPTODON
Group: Macropodidae
Length: 10 ft (3 m)

DIPROTODON
Group: Diprotodontidae
Length: 10 ft (3 m)

TOXODON
Group: Toxodontidae
Length: 10 ft (3 m)

MAMMUTHUS
Group: Elephantidae
Length: 10 ft (3 m)

THE EARTH DURING THE QUATERNARY PERIOD

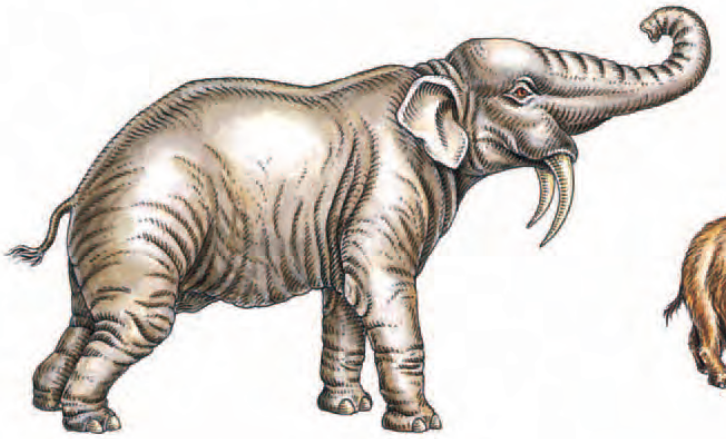
EXAMPLES OF QUATERNARY ANIMALS

A MAMMAL SKELETON
(Hippopotamus amphibius)

SKULL OF AN EXTINCT CAVE BEAR
(Ursus spelaeus)

SKULL OF AN EXTINCT TORTOISE
(Meiolania platyceps)

A MAMMOTH TOOTH
(Mammuthus primigenius)



DEINOTHERIUM
Group: Deinotheriidae
Length: 13 ft (4 m)

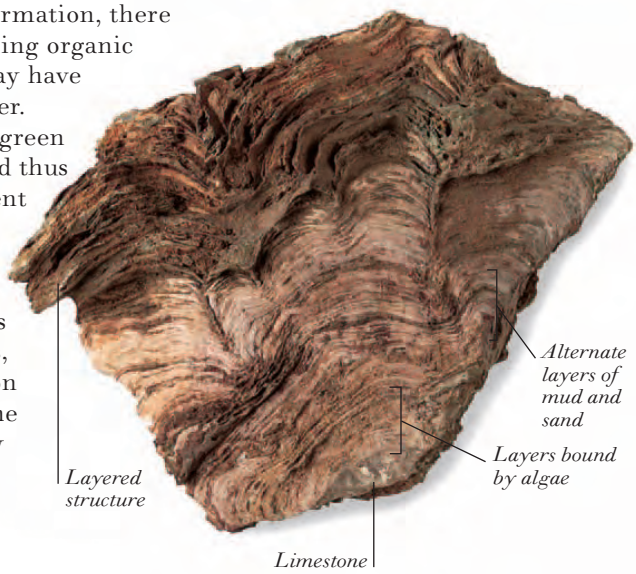
COELODONTA
Group: Rhinocerotidae
Length: 13 ft (4 m)

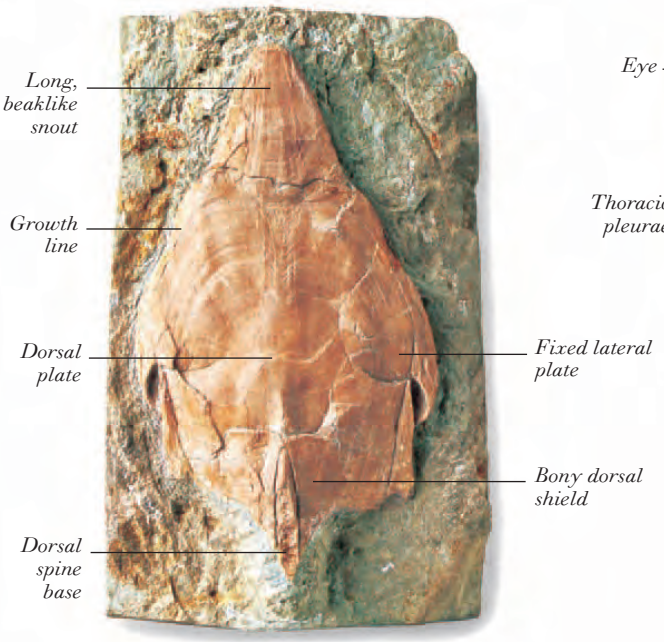
AUSTRALOPITHECUS
Group: Hominidae
Length: 4 ft (1.2 m)

Early signs of life

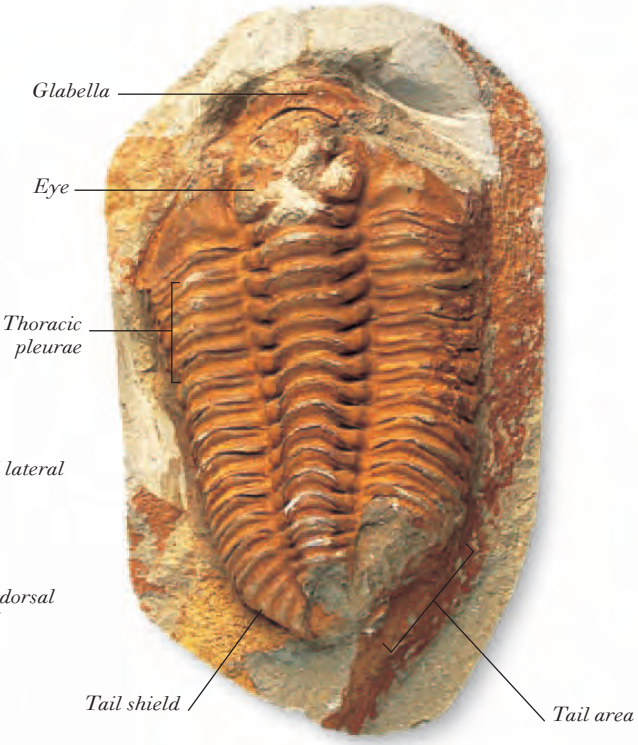
FOR ALMOST A THOUSAND MILLION YEARS after its formation, there was no known life on Earth. The first simple, sea-dwelling organic structures appeared about 3.5 billion years ago; they may have formed when certain chemical molecules joined together. Prokaryotes, single-celled microorganisms such as blue-green algae, were able to photosynthesize (see pp. 138–139), and thus produce oxygen. A thousand million years later, sufficient oxygen had built up in the Earth's atmosphere to allow multicellular organisms to proliferate in the Precambrian seas (before 570 million years ago). Soft-bodied jellyfish, corals, and seaworms flourished about 700 million years ago. Trilobites, the first animals with hard body frames, developed during the Cambrian period (570–510 million years ago). However, it was not until the beginning of the Devonian period (409–363 million years ago) that early land plants, such as *Asteroxylon*, formed a water-retaining cuticle, which ended their dependence on an aquatic environment. About 360 million years ago, the first amphibians (see pp. 80–81) crawled onto the land, although they probably still returned to the water to lay their soft eggs. By the time the first reptiles and synapsids appeared late in the Carboniferous, animals with backbones had become fully independent of water.

STROMATOLITIC LIMESTONE

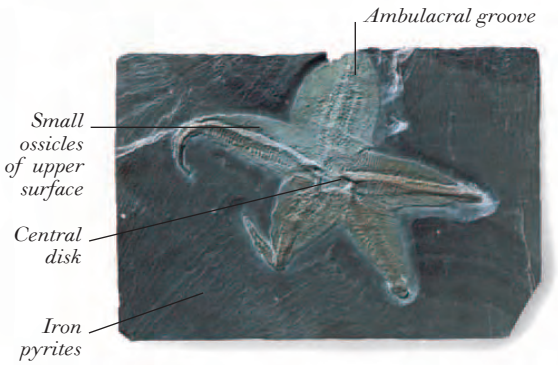




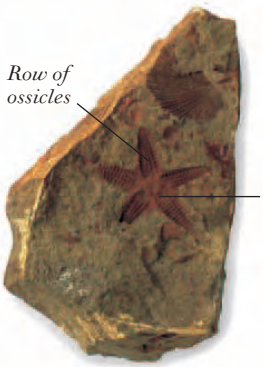
FOSSILIZED JAWLESS FISH



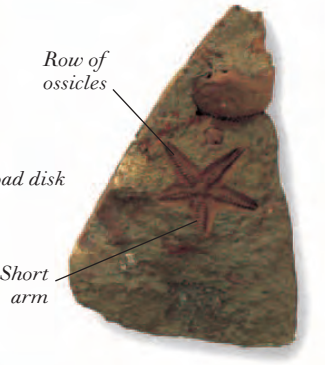
FOSSILIZED TRILOBITE



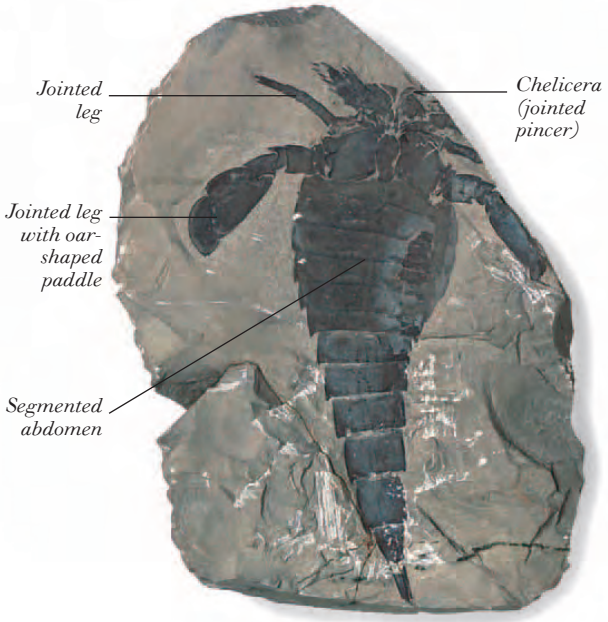
FOSSILIZED STARFISH



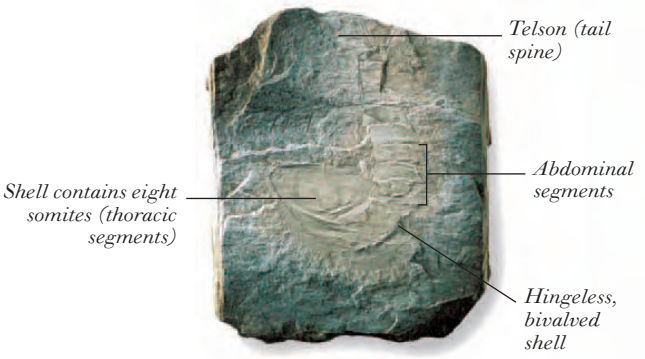
UPPER SURFACE OF FOSSILIZED STARFISH



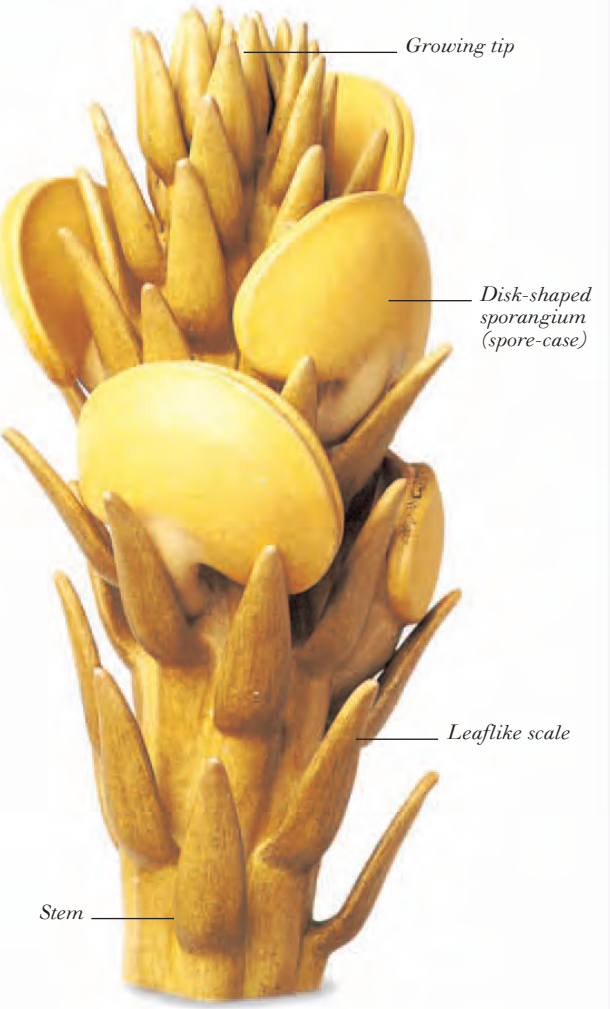
LOWER SURFACE OF FOSSILIZED STARFISH



UNDERSIDE OF FOSSILIZED EURYPTERID



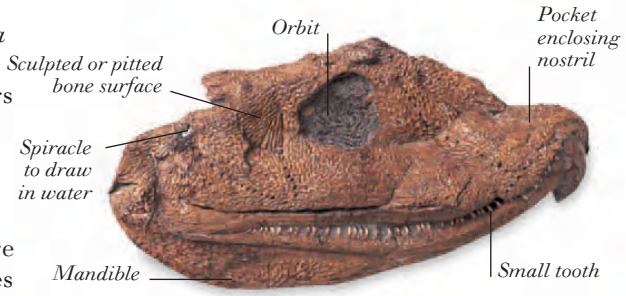
FOSSIL OF AN EXTINCT SHRIMP



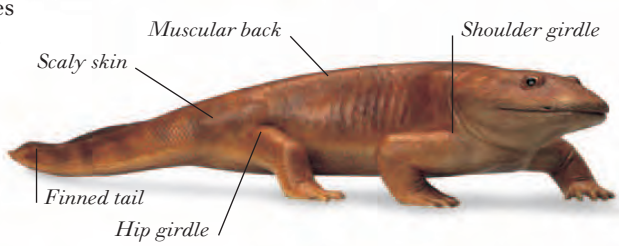
RECONSTRUCTION OF ASTEROXYLON

Amphibians and reptiles

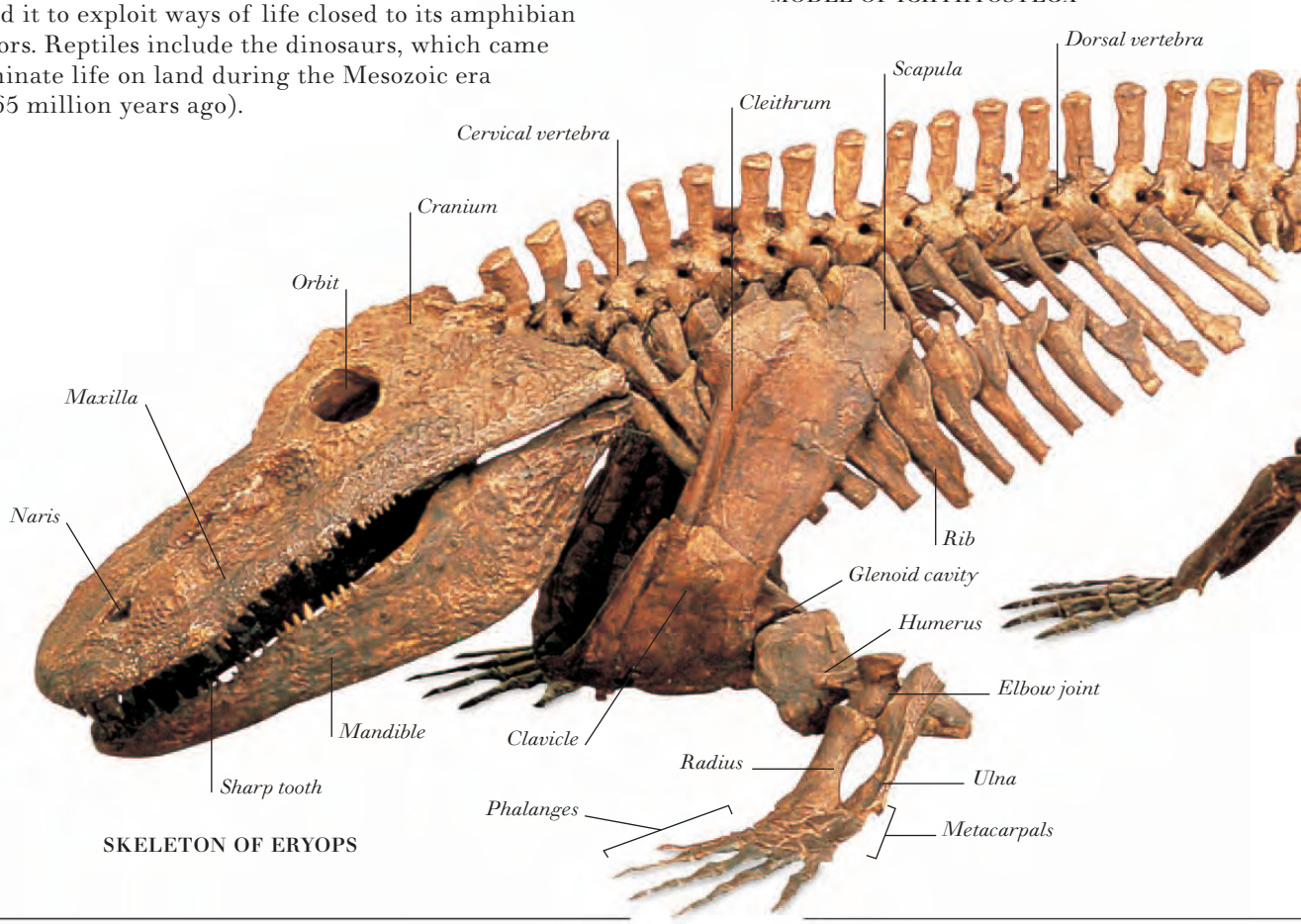
THE EARLIEST KNOWN AMPHIBIANS, such as *Acanthostega* and *Ichthyostega*, lived about 363 million years ago at the end of the Devonian period (409–363 million years ago). Their limbs may have evolved from the muscular fins of lungfishlike creatures. These fish can use their fins to push themselves along the bottom of lakes and some can breathe at the water's surface. While amphibians (see pp. 182–183) can exist on land, they are dependent on a wet environment because their skin does not retain moisture and most species must return to the water to lay their eggs. Evolving from amphibians, reptiles (see pp. 184–187) first appeared during the Carboniferous period (363–290 million years ago): *Westlothiana*, a possible early reptile, lived on land 338 million years ago. The development of the amniotic egg, with an embryo enclosed in its own wet environment (the amnion) and protected by a waterproof shell, freed reptiles from the amphibian's dependence on a wet habitat. A scaly skin protected the reptile from desiccation on land and enabled it to exploit ways of life closed to its amphibian ancestors. Reptiles include the dinosaurs, which came to dominate life on land during the Mesozoic era (245–65 million years ago).



FOSSIL SKULL OF ACANTHOSTEGA



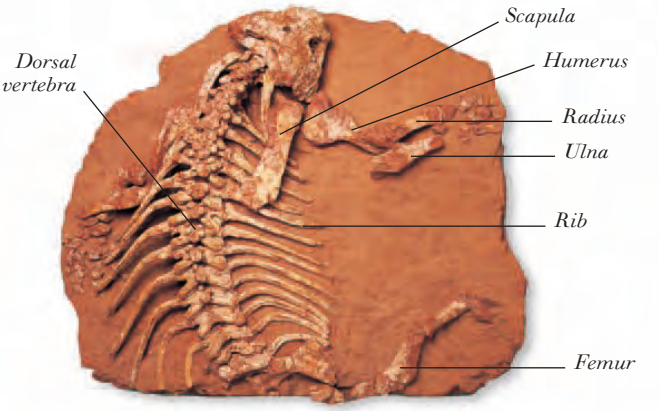
MODEL OF ICHTHYOSTEGA

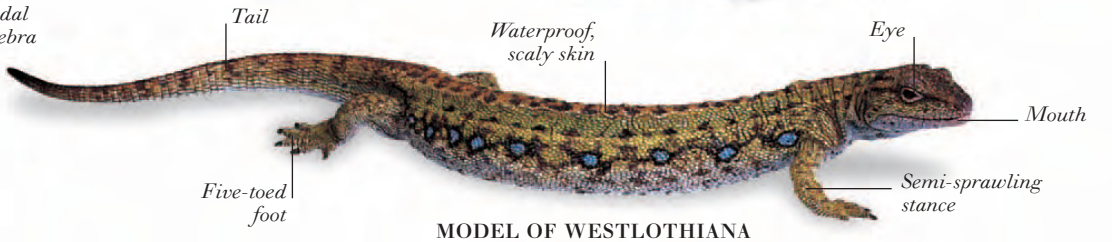


SKELETON OF ERYOPS

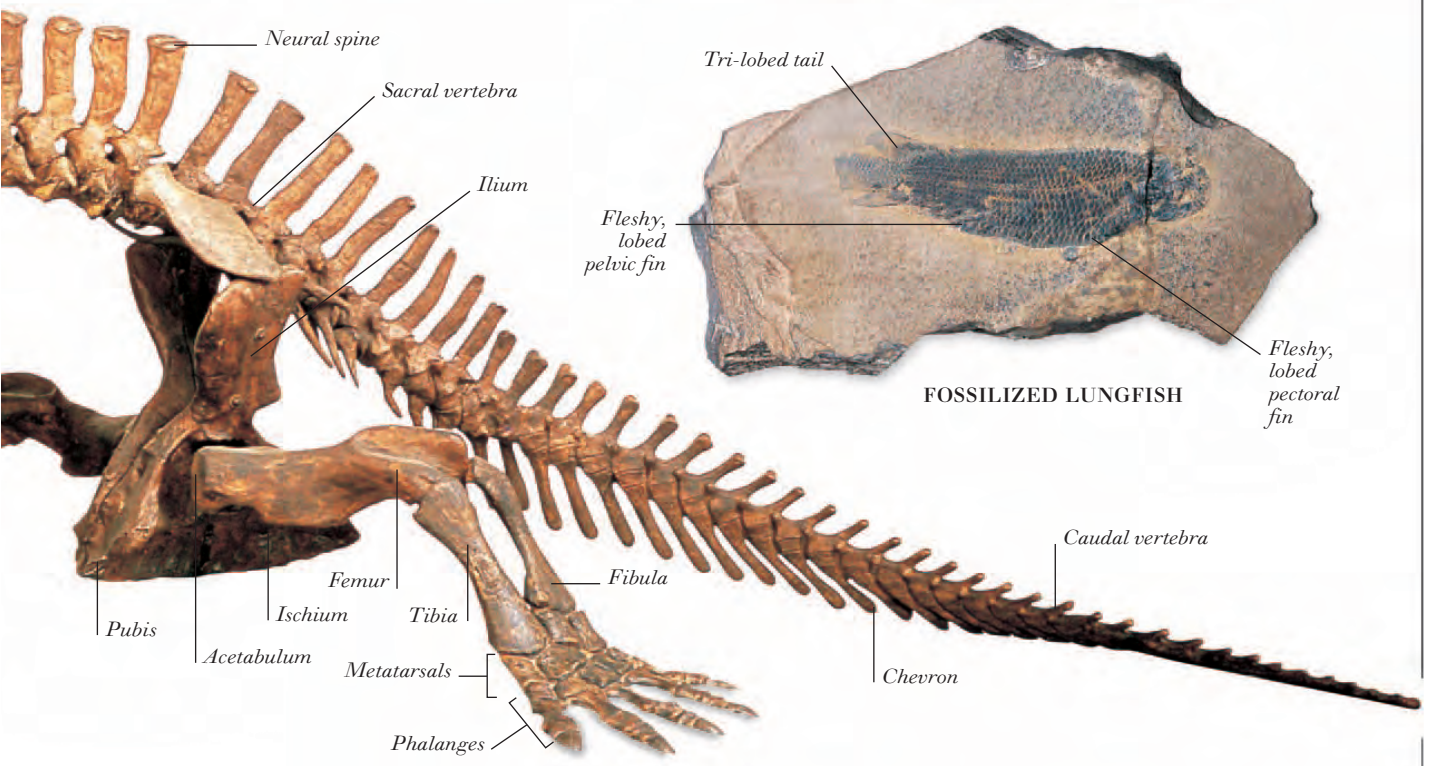
FOSSIL SKELETON OF WESTLOTHIANA

FOSSIL SKELETON OF A PAREIASAUR





MODEL OF WESTLOTHIANA

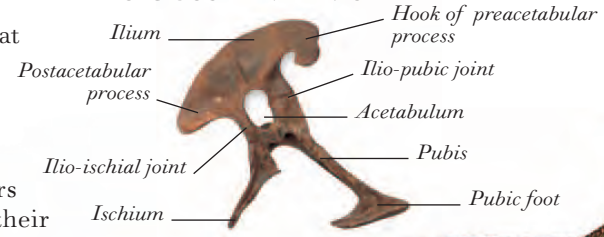


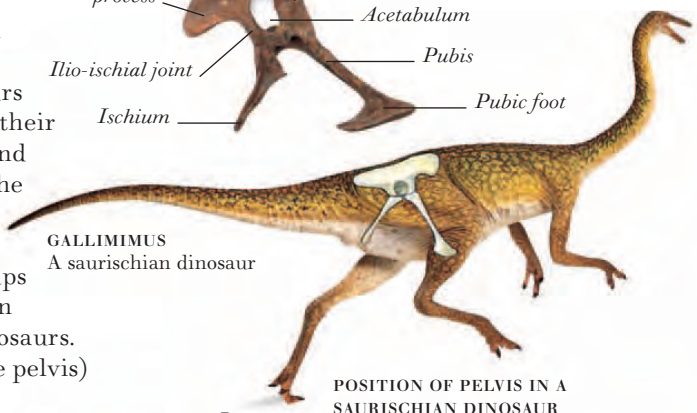
FOSSILIZED LUNGFISH

The dinosaurs

THE DINOSAURS WERE A LARGE GROUP of reptiles that were the dominant land vertebrates (animals with backbones) for most of the Mesozoic era (245–65 million years ago). They appeared some 230 million years ago and were distinguished from other scaly, egg-laying reptiles by an important feature: dinosaurs had an erect limb stance. This enabled them to keep their bodies well above the ground, unlike the sprawling and semisprawling stance of other reptiles. The head of the dinosaur's femur (thighbone) fit into a socket in its pelvis (hip-bone), producing efficient and mobile locomotion. Dinosaurs are categorized into two groups according to the structure of their pelvis: saurischian (lizard-hipped) and ornithischian (bird-hipped) dinosaurs. In the case of most saurischians, the pubis (part of the pelvis) jutted forward, while in ornithischians it slanted back, parallel to the ischium (another part of the pelvis). Dinosaurs ranged in size from smaller than a domestic cat to the biggest land animals ever known. The Dinosauria were the most successful land vertebrates ever, and survived for 165 million years, until most became extinct 65 million years ago.

STRUCTURE OF SAURISCHIAN PELVIS

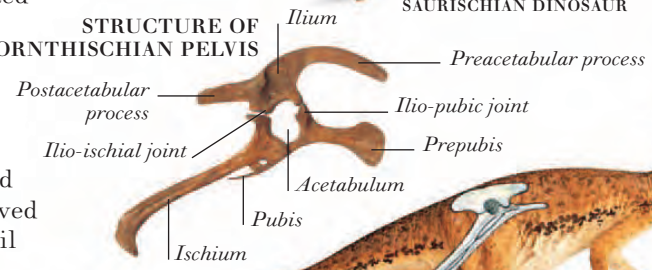


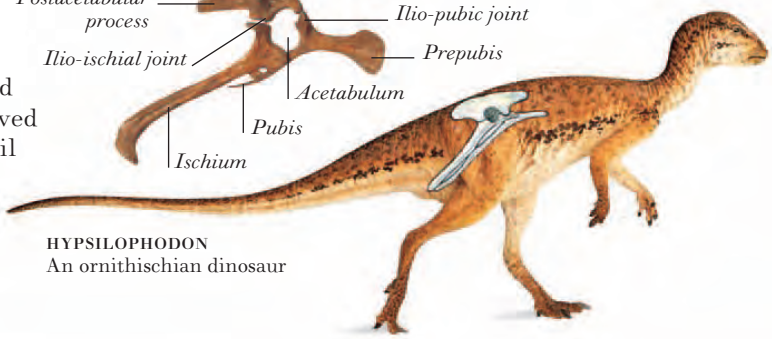


GALLIMIMUS
A saurischian dinosaur

POSITION OF PELVIS IN A SAURISCHIAN DINOSAUR

STRUCTURE OF ORNTHISCHIAN PELVIS





HYPSILOPHODON
An ornithischian dinosaur

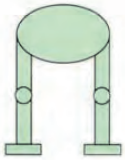
POSITION OF PELVIS IN AN ORNITHISCHIAN DINOSAUR

BAROSAURUS
A saurischian dinosaur

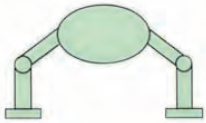
COMPARISON OF ANIMAL STANCES

SPRAWLING STANCE
The thighs and upper arms project straight out from the body so that the knees and elbows are bent at right angles.

COMMON IGUANA
(Iguana iguana)
A present-day reptile



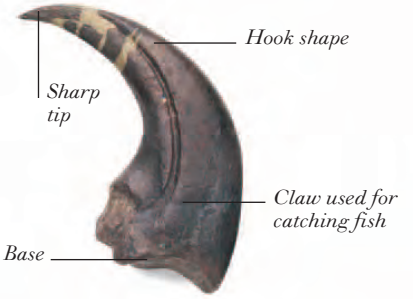
ERECT STANCE
The thighs and upper arms project straight down from the body so that the knees and elbows are straight.



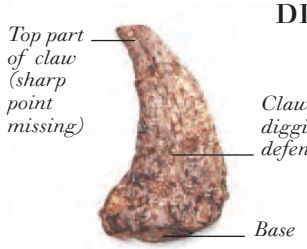
SEMISPRAWLING STANCE
The thighs and upper arms project downwards and outwards so that the knees and elbows are slightly bent.

DWARF CROCODILE
(Osteolaemus tetraspis)
A present-day reptile

EXAMPLES OF DINOSAUR CLAWS

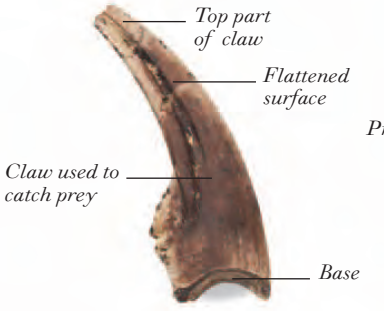


BARYONYX THUMB-CLAW



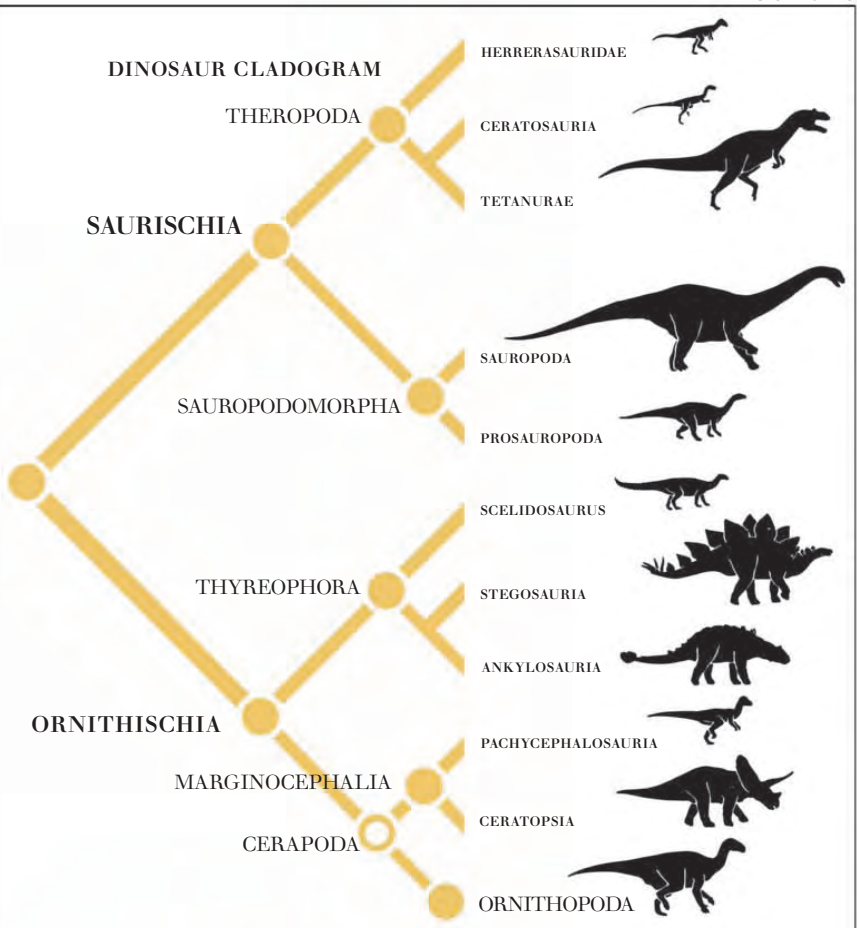
MASSOSPONDYLUS THUMB-CLAW

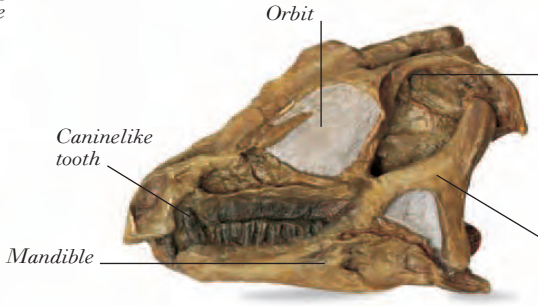
APATOSAURUS THUMB-CLAW



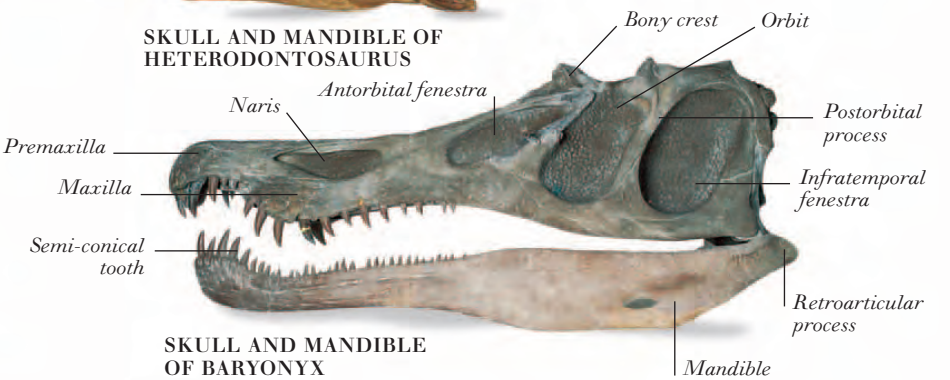
ORNITHOMIMUS FINGER-CLAW

DINOSAUR CLADOGRAM





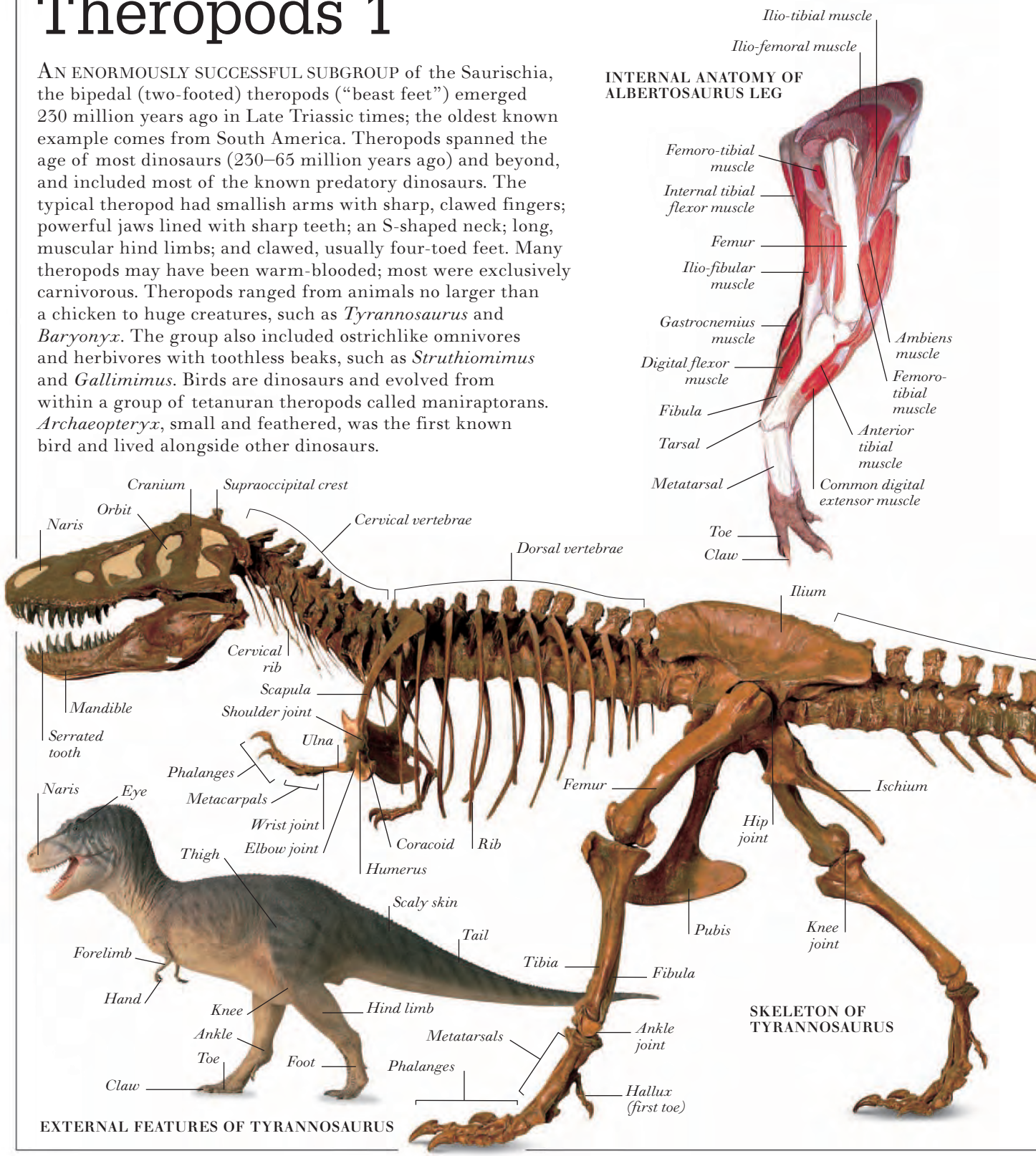
SKULL AND MANDIBLE OF HETERODONTOSAURUS



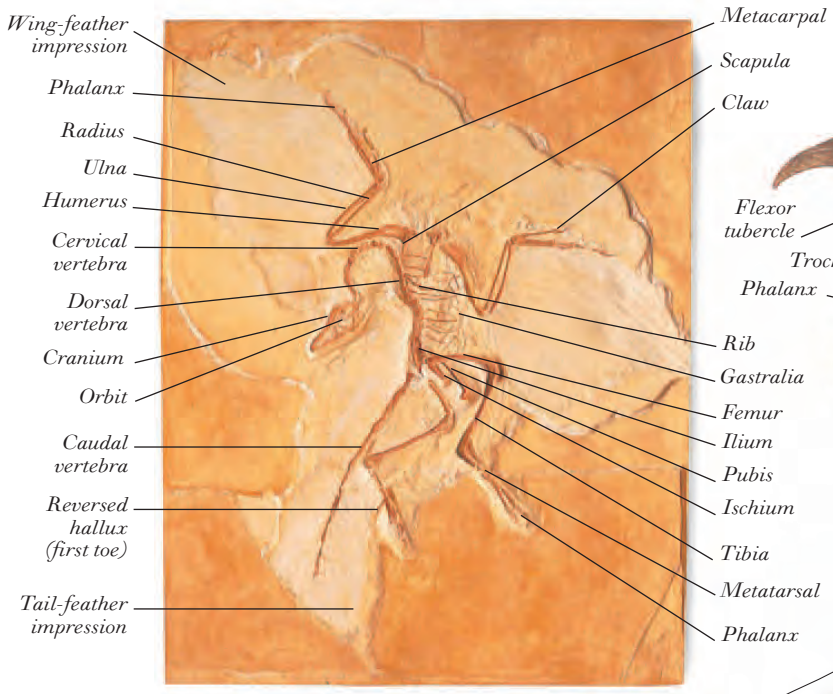
SKULL AND MANDIBLE OF BARYONYX

Theropods 1

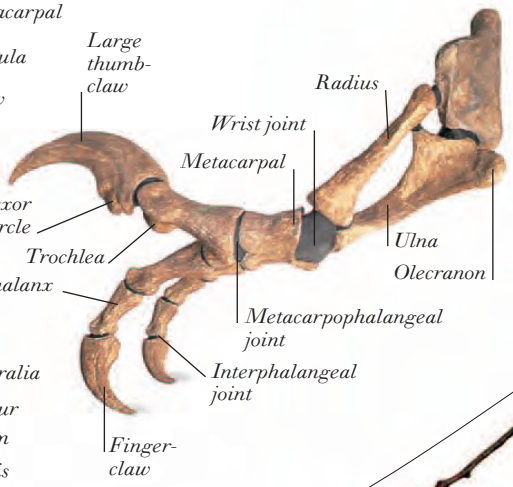
AN ENORMOUSLY SUCCESSFUL SUBGROUP of the Saurischia, the bipedal (two-footed) theropods ("beast feet") emerged 230 million years ago in Late Triassic times; the oldest known example comes from South America. Theropods spanned the age of most dinosaurs (230–65 million years ago) and beyond, and included most of the known predatory dinosaurs. The typical theropod had smallish arms with sharp, clawed fingers; powerful jaws lined with sharp teeth; an S-shaped neck; long, muscular hind limbs; and clawed, usually four-toed feet. Many theropods may have been warm-blooded; most were exclusively carnivorous. Theropods ranged from animals no larger than a chicken to huge creatures, such as *Tyrannosaurus* and *Baryonyx*. The group also included ostrichlike omnivores and herbivores with toothless beaks, such as *Struthiomimus* and *Gallimimus*. Birds are dinosaurs and evolved from within a group of tetanuran theropods called maniraptorans. *Archaeopteryx*, small and feathered, was the first known bird and lived alongside other dinosaurs.

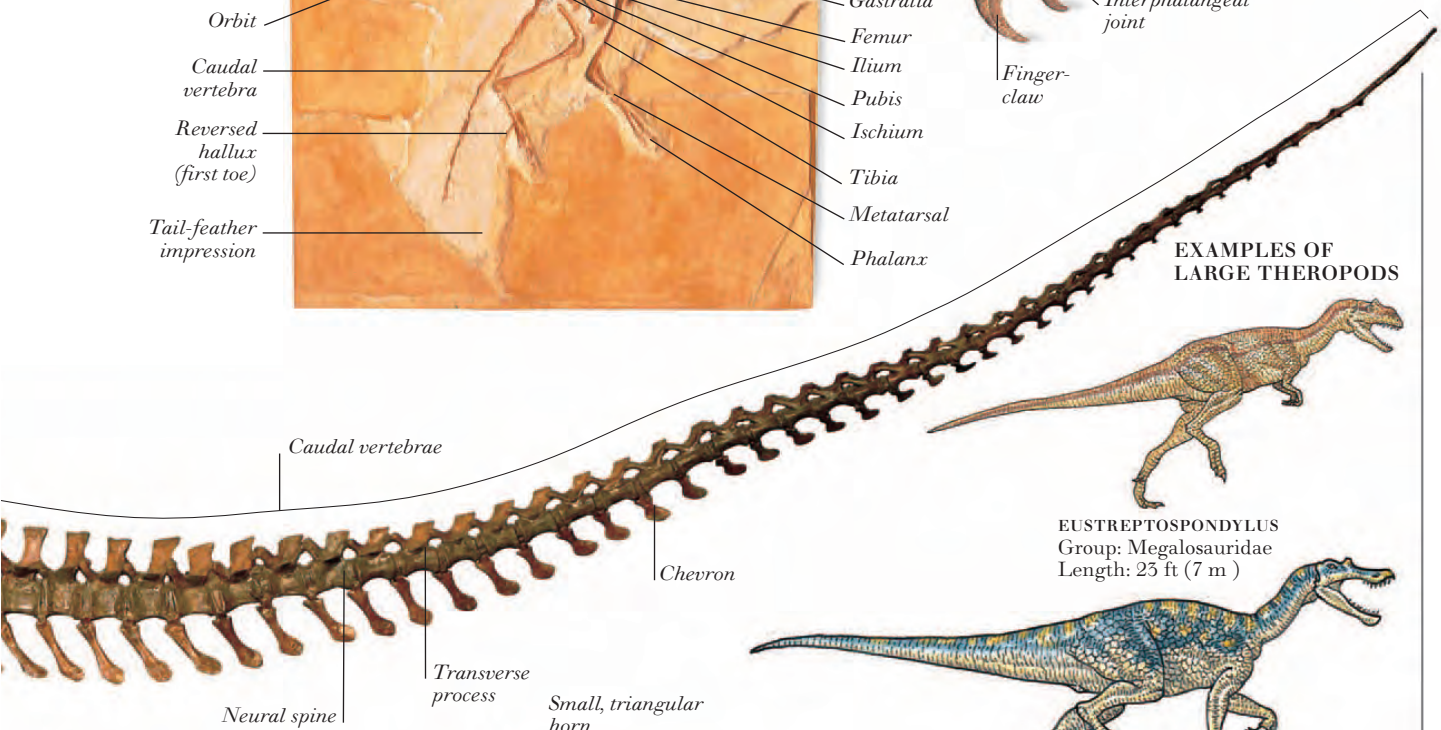


FOSSIL SKELETON OF ARCHAEOPTERYX



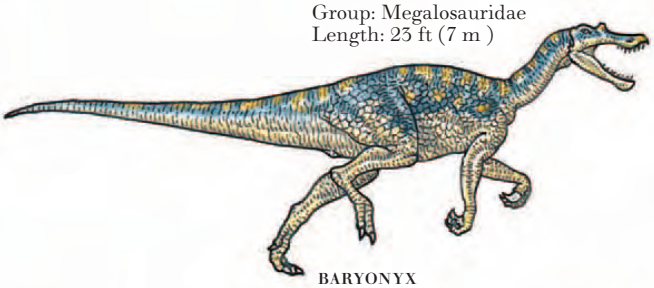
SKELETON OF BARYONYX HAND



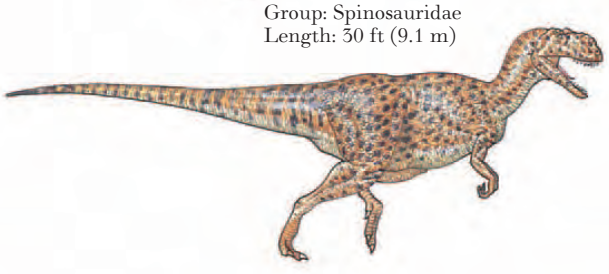


EXAMPLES OF LARGE THEROPODS

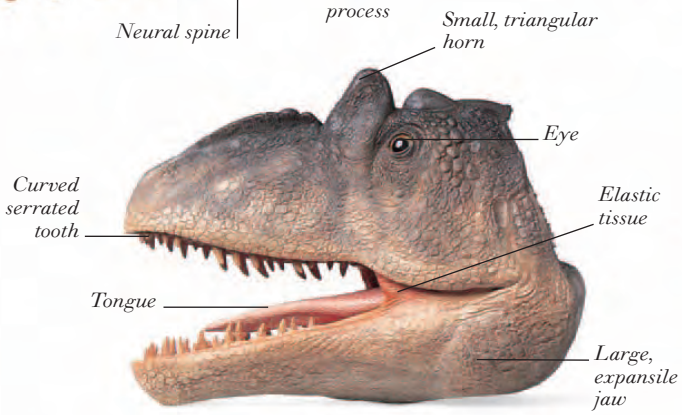
EUSTREPTOSPONDYLUS
Group: Megalosauridae
Length: 23 ft (7 m)



BARYONYX
Group: Spinosauridae
Length: 30 ft (9.1 m)

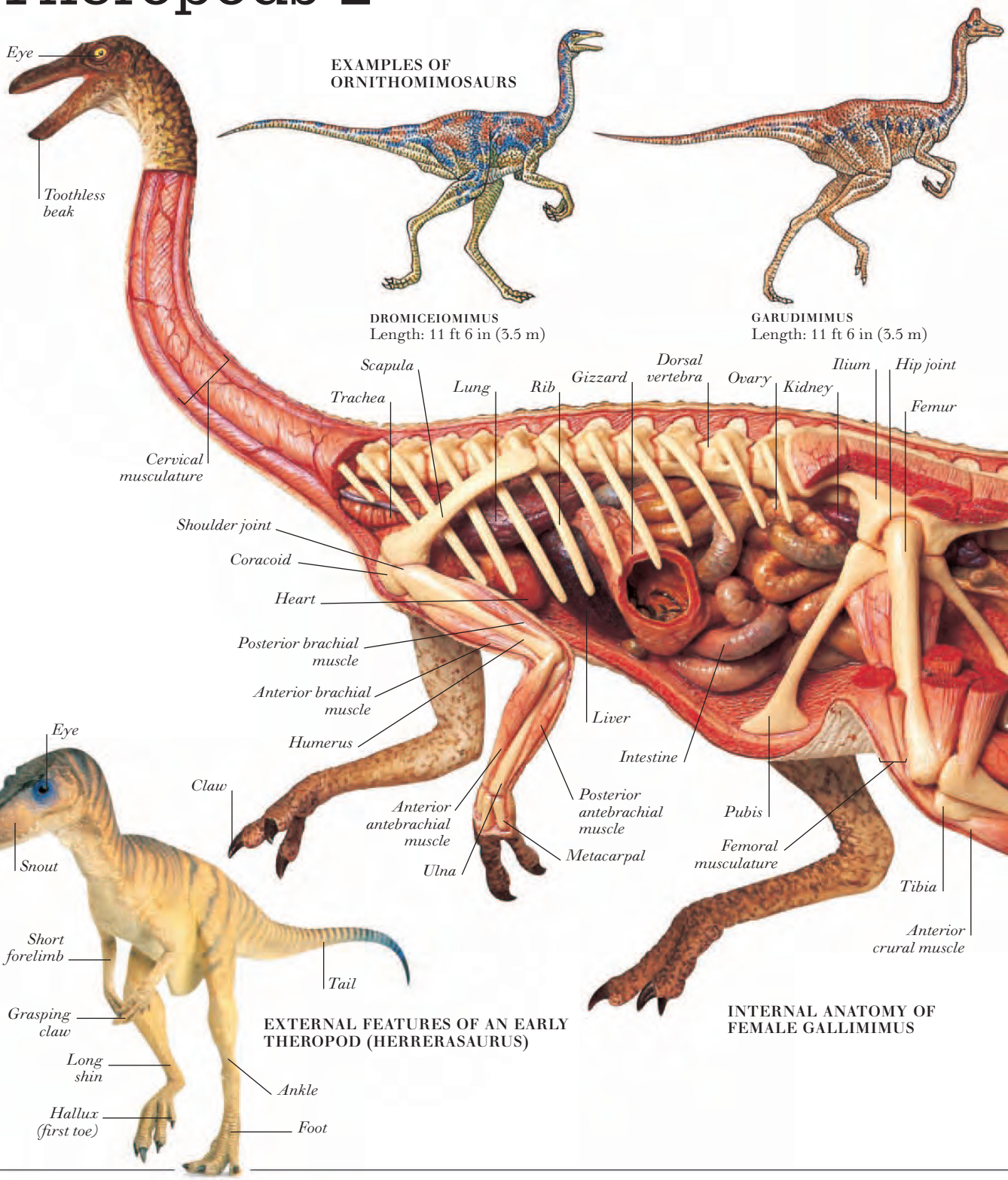


YANGCHUANOSAURUS
Group: Sinraptoridae
Length: 33 ft (10 m)



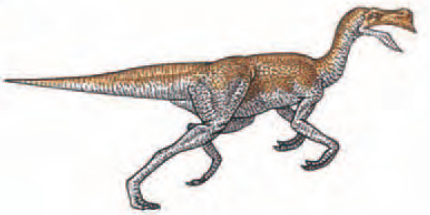
HEAD OF ALLOSAURUS

Theropods 2


Eye
Toothless beak
Cervical musculature
EXAMPLES OF ORNITHOMIMOSAURS
DROMICEIOMIMUS
Length: 11 ft 6 in (3.5 m)
GARUDIMIMUS
Length: 11 ft 6 in (3.5 m)
Scapula
Trachea
Lung
Rib
Gizzard
Dorsal vertebra
Ovary
Kidney
Ilium
Hip joint
Femur
Shoulder joint
Coracoid
Heart
Posterior brachial muscle
Anterior brachial muscle
Humerus
Liver
Intestine
Claw
Anterior antebrachial muscle
Posterior antebrachial muscle
Ulna
Metacarpal
Pubis
Femoral musculature
Tibia
Anterior crural muscle
Eye
Snout
Short forelimb
Tail
Grasping claw
Long shin
Ankle
Hallux (first toe)
Foot
EXTERNAL FEATURES OF AN EARLY THEROPOD (HERRERASAURUS)
INTERNAL ANATOMY OF FEMALE GALLIMIMUS

EXAMPLES OF SMALL THEROPODS

STRUTHIOMIMUS
Length: 11 ft 6 in (3.5 m)

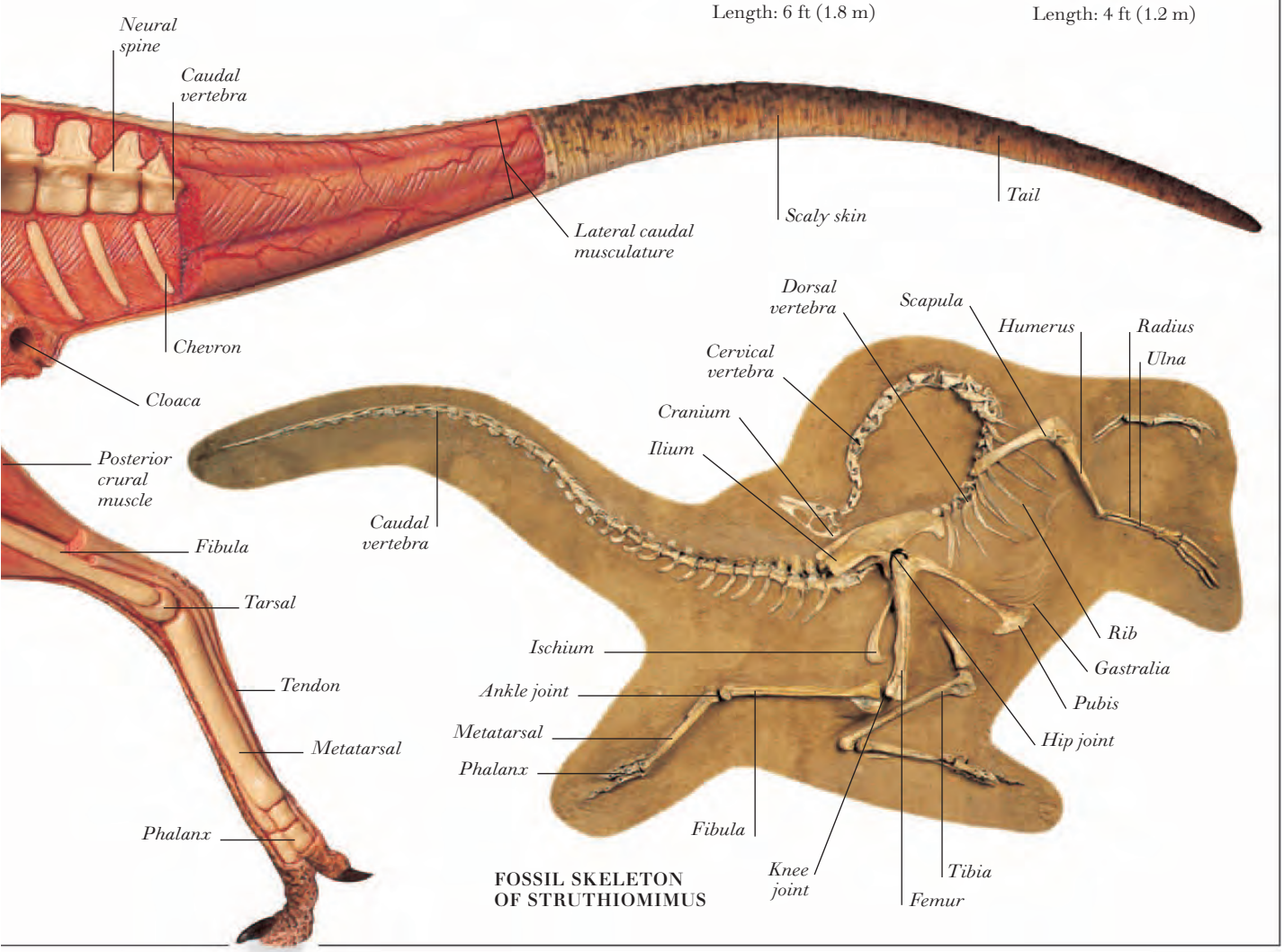


CHIROSTENOTES
Length: 6 ft 6 in (2 m)

AVIMIMUS
Length: 5 ft (1.5 m)

COELURUS
Length: 6 ft (1.8 m)

PROCOMPSOGNATHUS
Length: 4 ft (1.2 m)



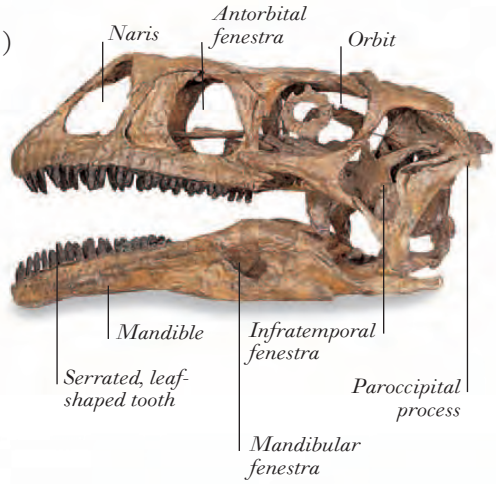
FOSSIL SKELETON OF STRUTHIOMIMUS

Sauropodomorphs 1

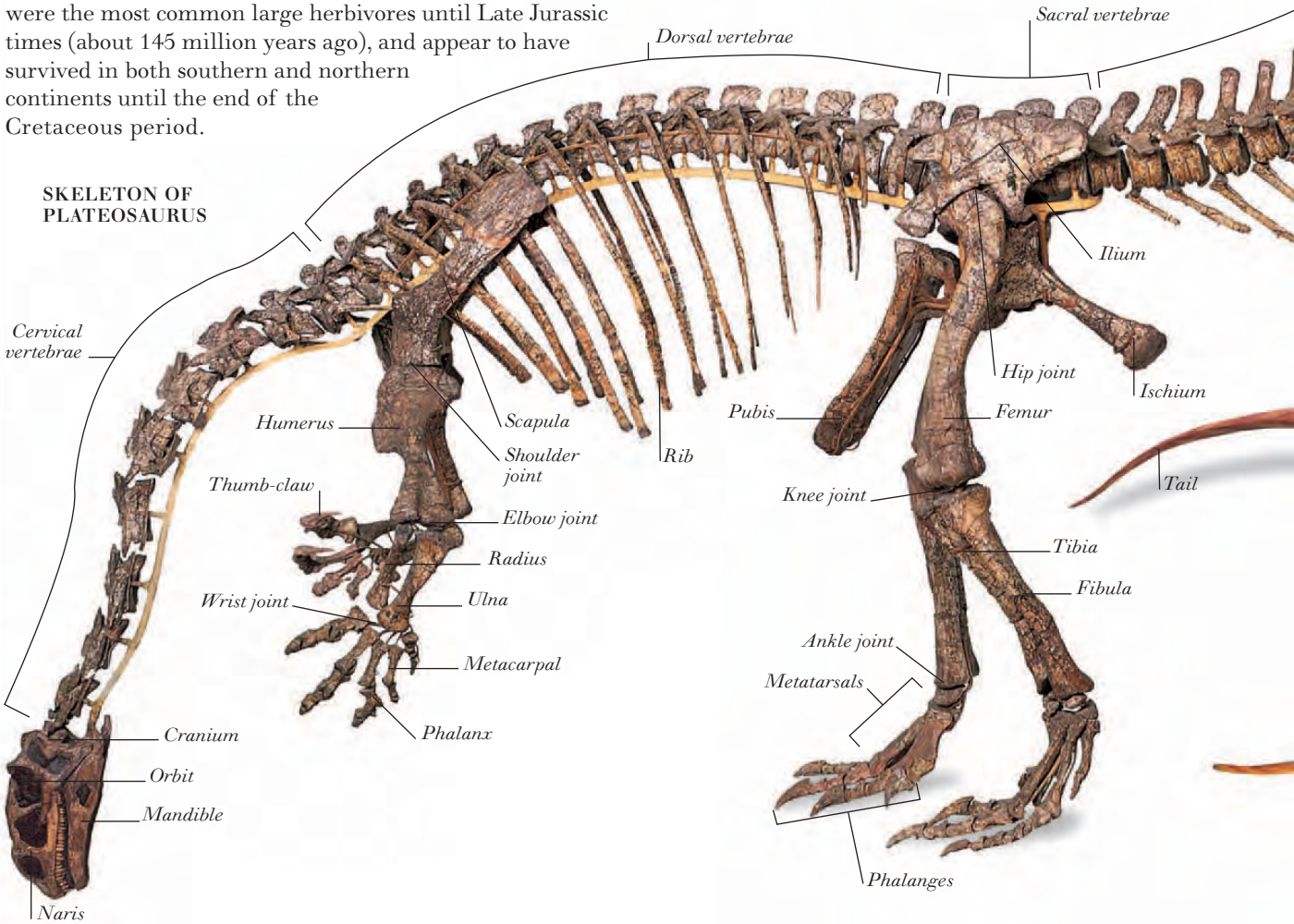
THECODONTOSAURUS

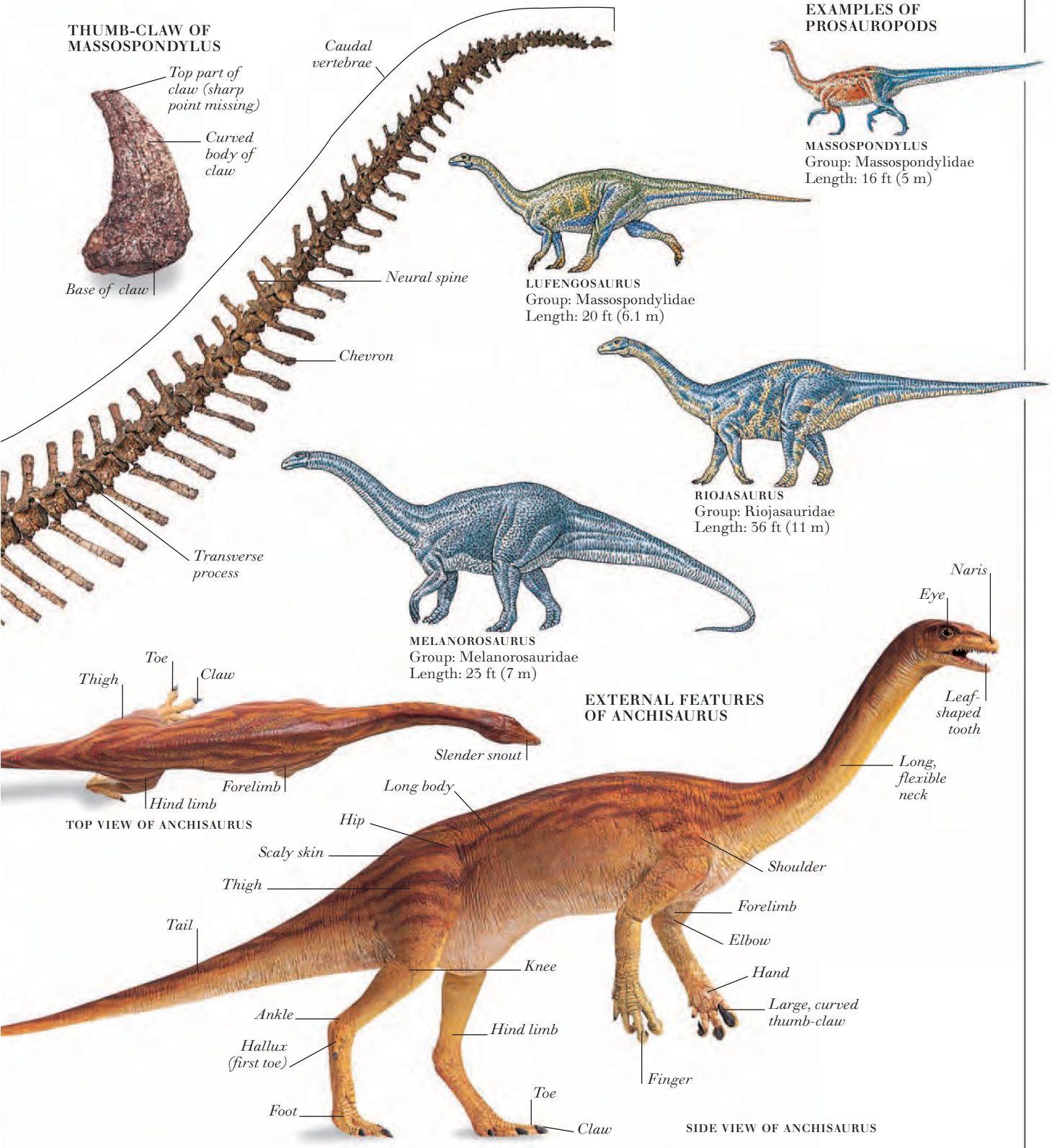
THE SAUROPODOMORPHA ("lizard-feet forms") were herbivorous, usually quadrupedal (four-footed) dinosaurs. A suborder of the Saurischia, they were characterized by small heads, bulky bodies, and long necks and tails. Sauropodomorphs have often been split into two groups: prosauropods and sauropods. Prosauropods lived from Late Triassic to Early Jurassic times (225–180 million years ago) and included beasts such as the small *Anchisaurus* and one of the first very large dinosaurs, *Plateosaurus*. By Middle Jurassic times (about 165 million years ago), sauropods had replaced prosauropods and spread worldwide. They included the heaviest and longest land animals ever, such as *Diplodocus* and *Brachiosaurus*. Sauropods persisted to the end of the Cretaceous period (65 million years ago). Many of these dinosaurs moved in herds, protected from predatory theropods by their huge bulk and powerful tails, which they could use to lash out at attackers. Sauropodomorphs were the most common large herbivores until Late Jurassic times (about 145 million years ago), and appear to have survived in both southern and northern continents until the end of the Cretaceous period.

SKULL AND MANDIBLE OF PLATEOSAURUS

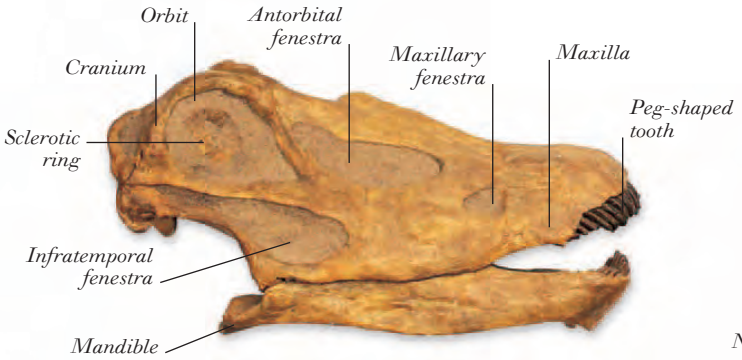


SKELETON OF PLATEOSAURUS




THUMB-CLAW OF MASSOSPONDYLUS
Top part of claw (sharp point missing)
Curved body of claw
Base of claw
Caudal vertebrae
Neural spine
Chevron
Transverse process
EXAMPLES OF PROSAUROPODS
MASSOSPONDYLUS
Group: Massospondylidae
Length: 16 ft (5 m)
LUFENGOSAURUS
Group: Massospondylidae
Length: 20 ft (6.1 m)
RIOJASAURUS
Group: Riojasauridae
Length: 36 ft (11 m)
MELANOROSAURUS
Group: Melanorosauridae
Length: 23 ft (7 m)
Toe
Thigh
Claw
Forelimb
Hind limb
TOP VIEW OF ANCHISAURUS
EXTERNAL FEATURES OF ANCHISAURUS
Naris
Eye
Leaf-shaped tooth
Slender snout
Long, flexible neck
Long body
Hip
Scaly skin
Thigh
Tail
Shoulder
Forelimb
Elbow
Hand
Large, curved thumb-claw
Knee
Ankle
Hind limb
Hallux (first toe)
Finger
Toe
Foot
Claw
SIDE VIEW OF ANCHISAURUS

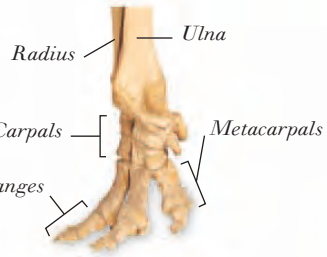
Sauropodomorphs 2



SKULL AND MANDIBLE OF DIPLODOCUS

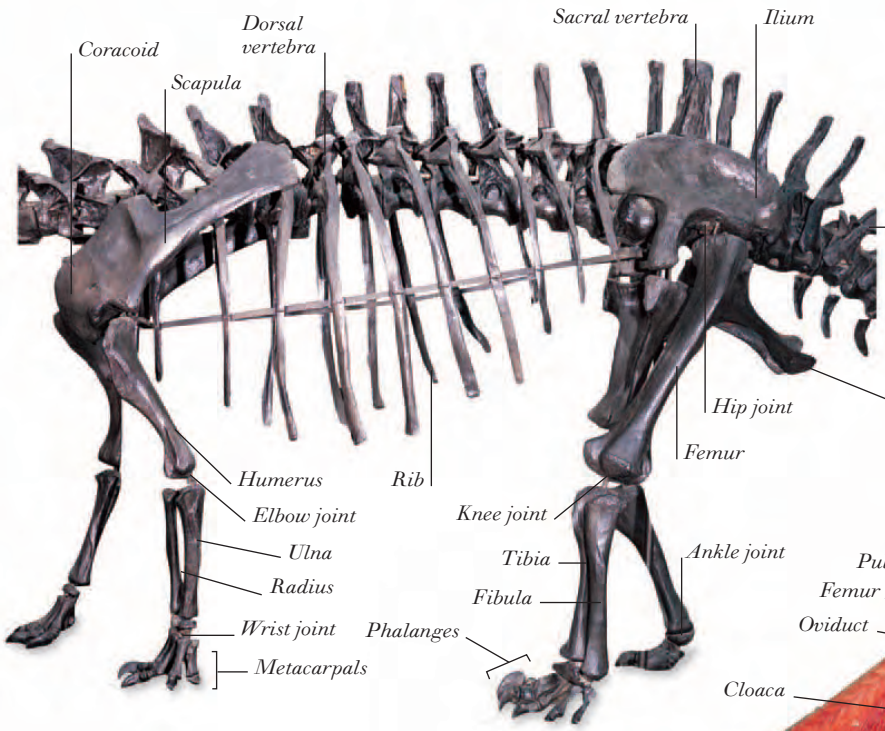
FOREFOOT OF ELEPHANT

FOREFOOT BONES OF ELEPHANT

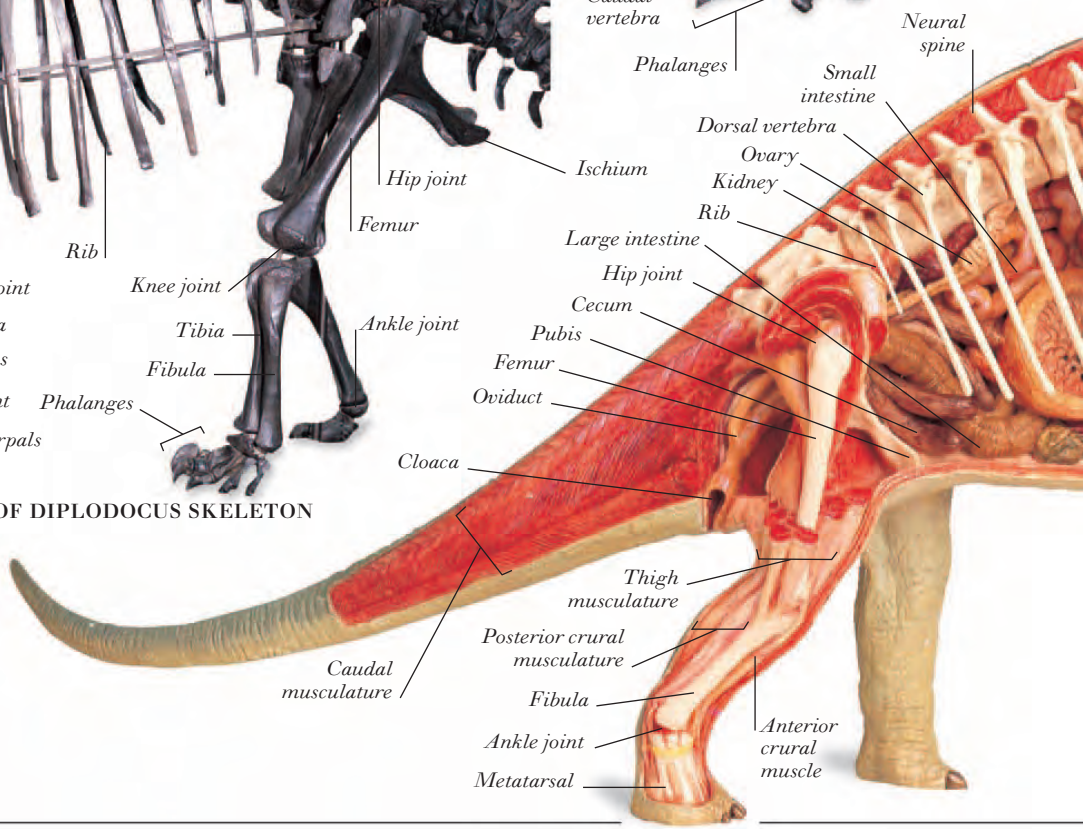


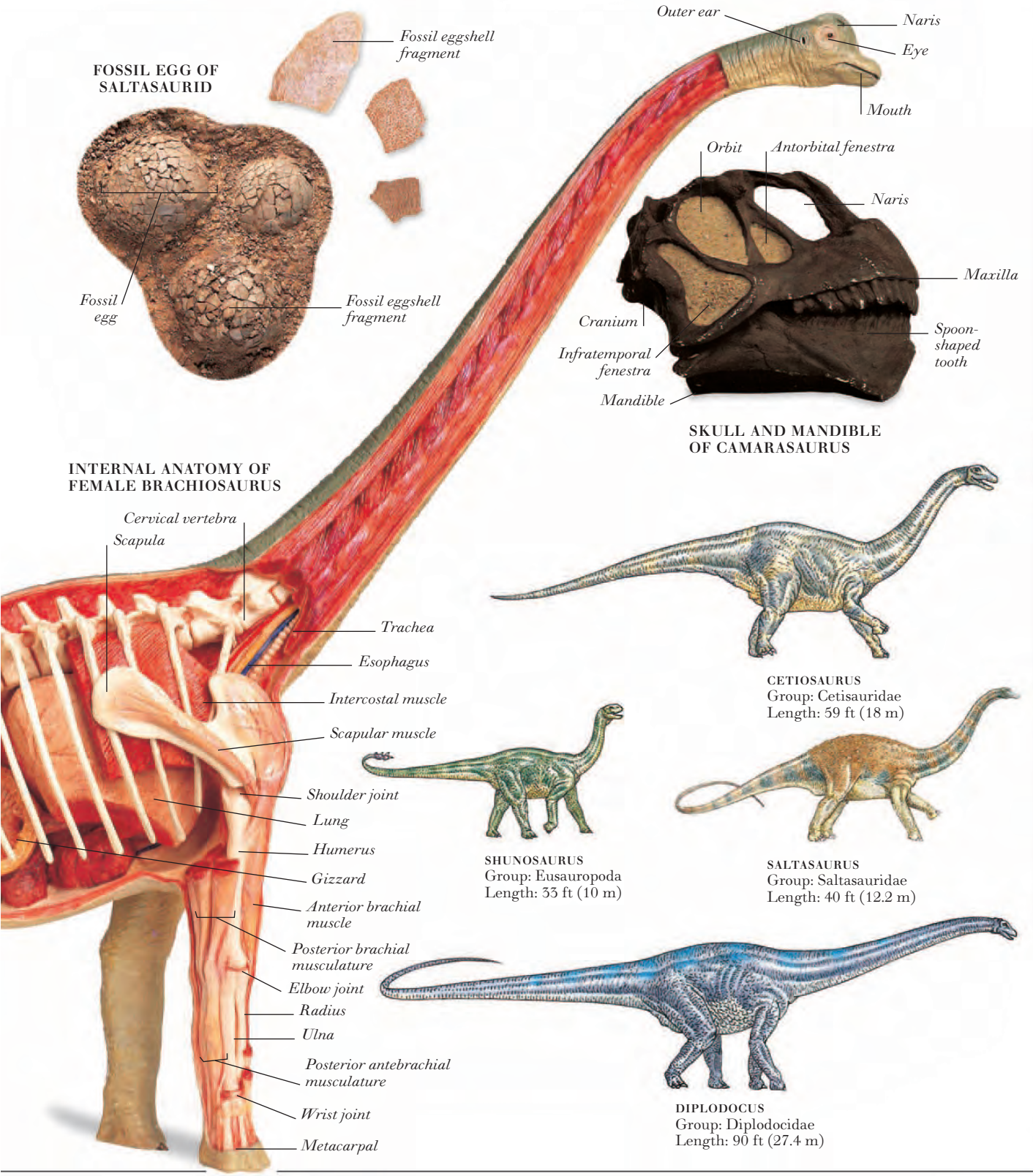
COMPARISON OF THE FOREFEET OF AN ELEPHANT AND DIPLODOCUS

FOREFOOT BONES OF DIPLODOCUS



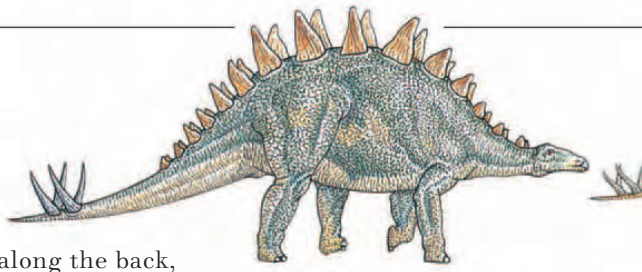
MIDDLE SECTION OF DIPLODOCUS SKELETON



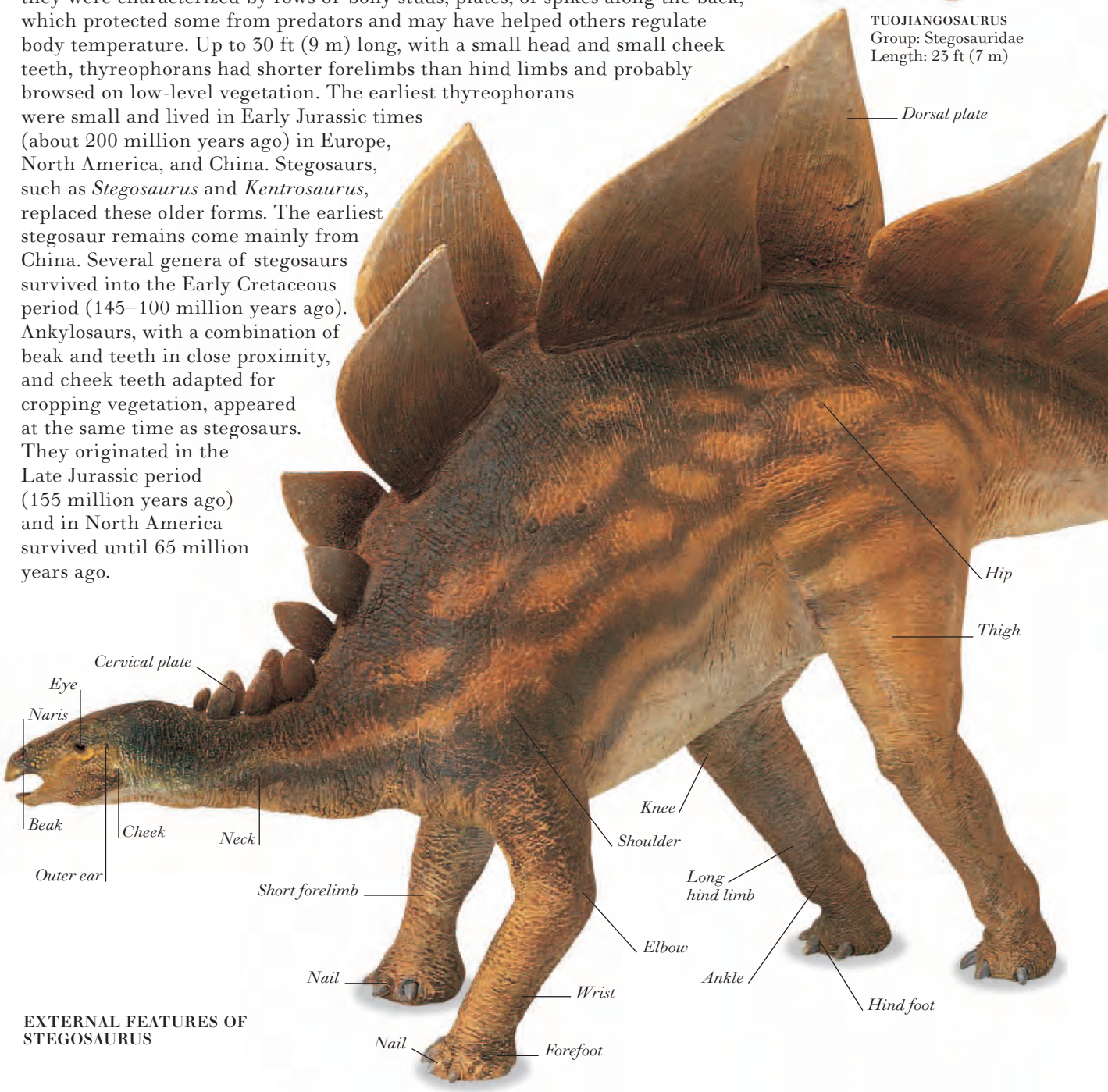

FOSSIL EGG OF SALTASAURID
Fossil eggshell fragment
Fossil egg
Fossil eggshell fragment
Outer ear
Naris
Eye
Mouth
Orbit
Antorbital fenestra
Naris
Maxilla
Cranium
Spoon-shaped tooth
Infratemporal fenestra
Mandible
SKULL AND MANDIBLE OF CAMARASAURUS
INTERNAL ANATOMY OF FEMALE BRACHIOSAURUS
Cervical vertebra
Scapula
Trachea
Esophagus
Intercostal muscle
Scapular muscle
Shoulder joint
Lung
Humerus
Gizzard
Anterior brachial muscle
Posterior brachial musculature
Elbow joint
Radius
Ulna
Posterior antebrachial musculature
Wrist joint
Metacarpal
CETIOSAURUS
Group: Cetisauridae
Length: 59 ft (18 m)
SHUNOSAURUS
Group: Eusauropoda
Length: 33 ft (10 m)
SALTASAURUS
Group: Saltasauridae
Length: 40 ft (12.2 m)
DIPLODOCUS
Group: Diplodocidae
Length: 90 ft (27.4 m)

Thyreophorans 1

THYREOPHORANS ("SHIELD BEARERS") were a group of quadrupedal armored dinosaurs. They were one clade among several within the Ornithischia (bird-hipped dinosaurs), they were characterized by rows of bony studs, plates, or spikes along the back, which protected some from predators and may have helped others regulate body temperature. Up to 30 ft (9 m) long, with a small head and small cheek teeth, thyreophorans had shorter forelimbs than hind limbs and probably browsed on low-level vegetation. The earliest thyreophorans were small and lived in Early Jurassic times (about 200 million years ago) in Europe, North America, and China. Stegosaurs, such as *Stegosaurus* and *Kentrosaurus*, replaced these older forms. The earliest stegosaur remains come mainly from China. Several genera of stegosaurs survived into the Early Cretaceous period (145–100 million years ago). Ankylosaurs, with a combination of beak and teeth in close proximity, and cheek teeth adapted for cropping vegetation, appeared at the same time as stegosaurs. They originated in the Late Jurassic period (155 million years ago) and in North America survived until 65 million years ago.

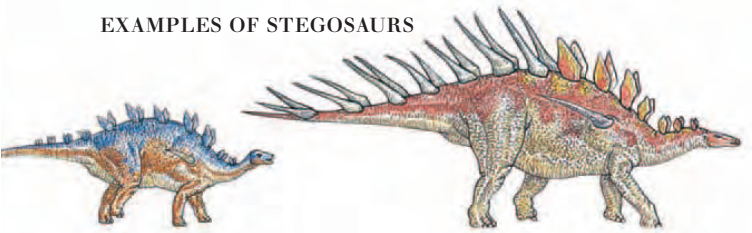


TUOJIANGOSAURUS
Group: Stegosauridae
Length: 23 ft (7 m)



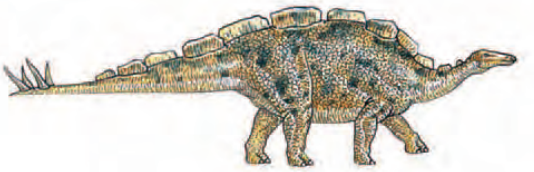
EXTERNAL FEATURES OF STEGOSAURUS

EXAMPLES OF STEGOSAURS



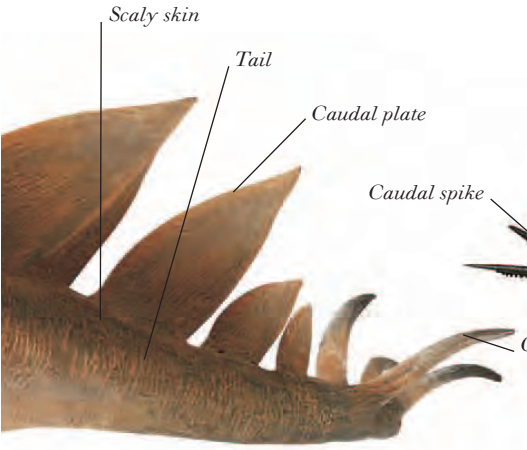
HUAYANGOSAURUS
Group: Huayangosauridae
Length: 13 ft (4 m)

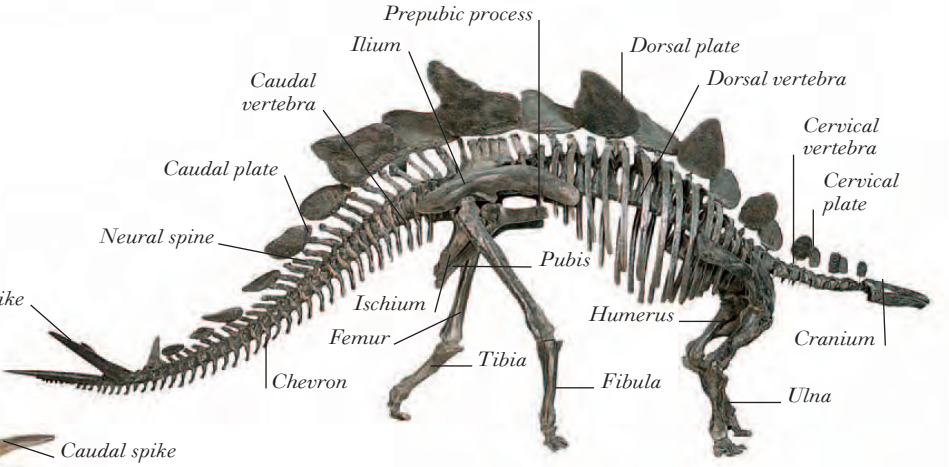
KENTROSAURUS
Group: Stegosauridae
Length: 16 ft (4.9 m)



WUERHOSAURUS
Group: Stegosauridae
Length: 20 ft (6.1 m)

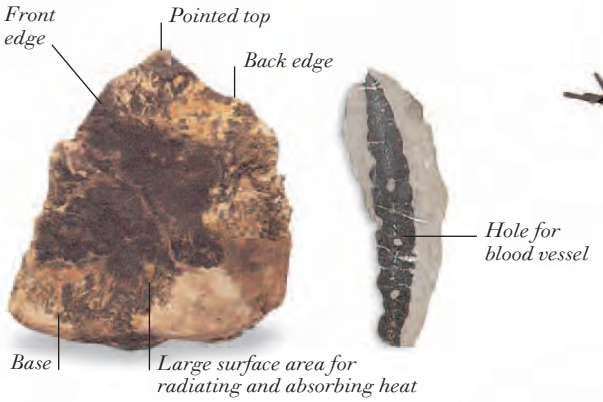
EXAMPLES OF STEGOSAUR SKELETONS





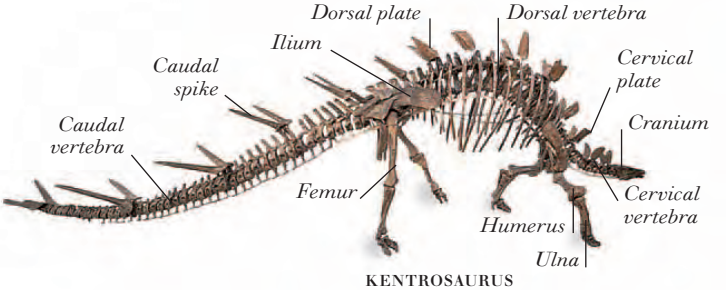
STEGOSAURUS

DORSAL PLATE OF STEGOSAURUS

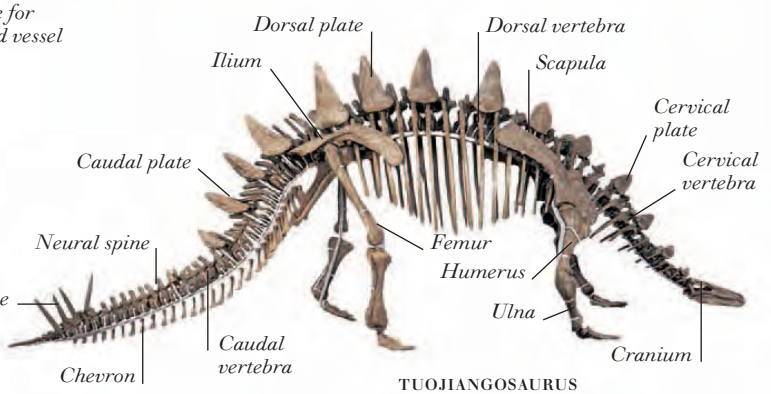


SIDE VIEW OF DORSAL PLATE

SECTION THROUGH DORSAL PLATE

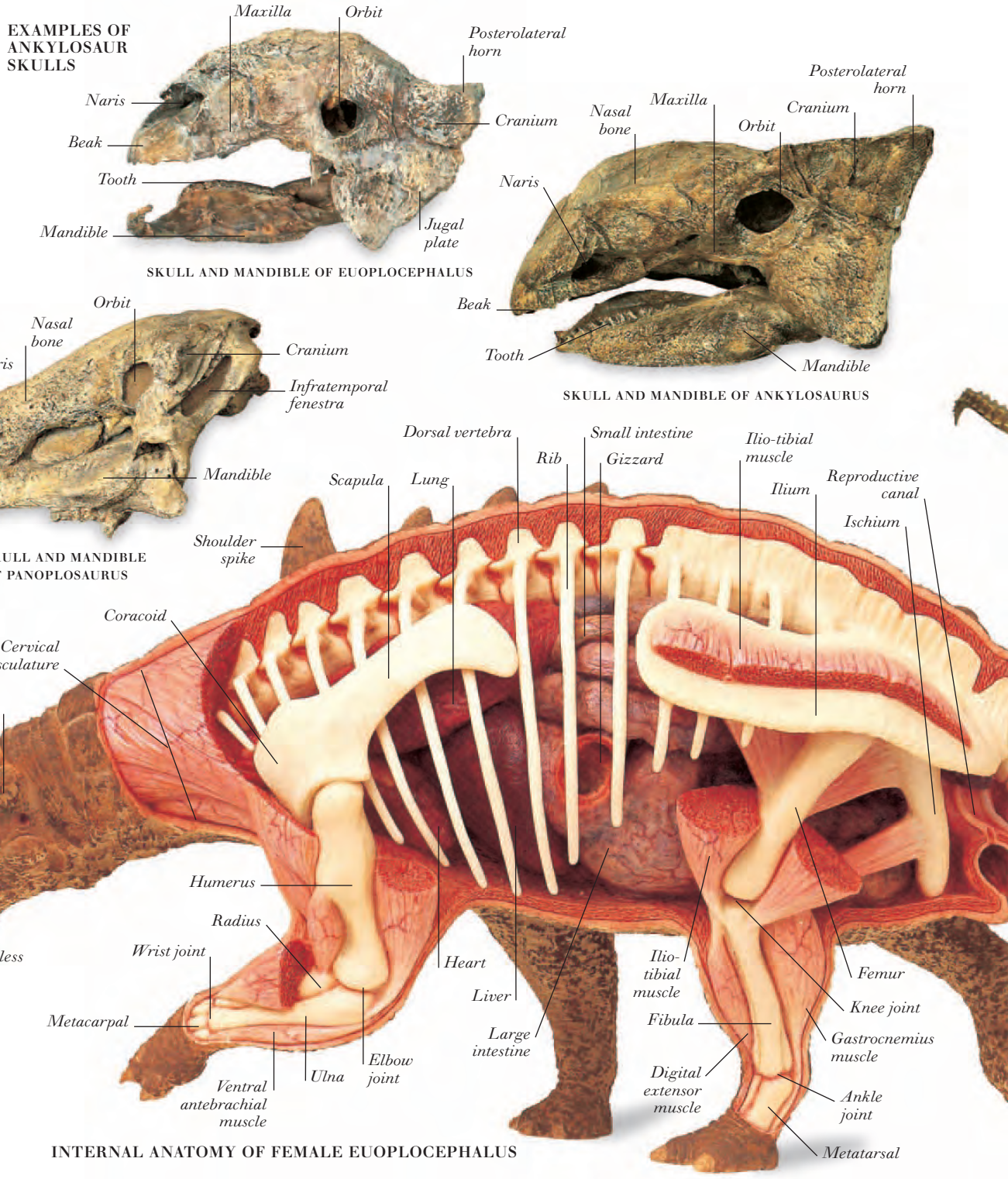


KENTROSAURUS

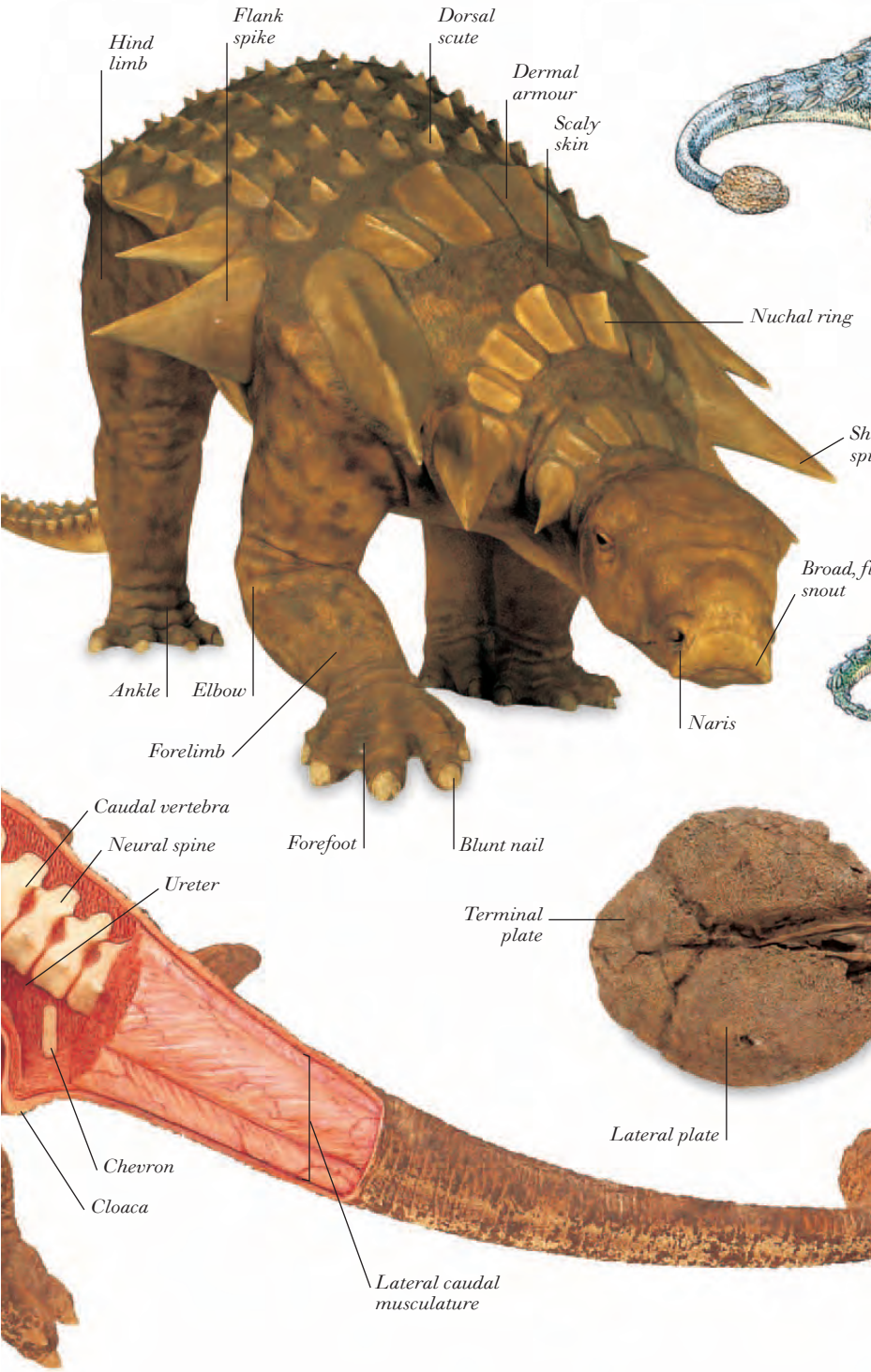


TUOJIANGOSAURUS

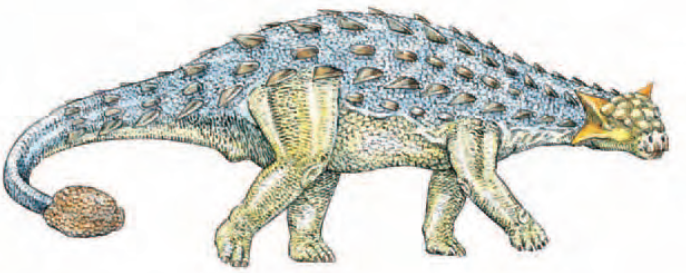
Thyreophorans 2



EXTERNAL FEATURES OF EDMONTONIA



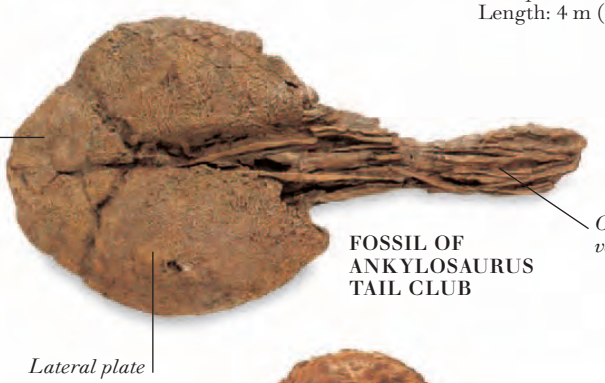
EXAMPLES OF ANKYLOSAURS



PINACOSAURUS
Group: Ankylosauridae
Length: 5 m (16 ft 6 in)

MINMI
Group: Ankylosauria
Length: 2.4 m (8 ft)

POLACANTHUS
Group: Polacanthidae
Length: 4 m (13 ft)



FOSSIL OF ANKYLOSAURUS TAIL CLUB

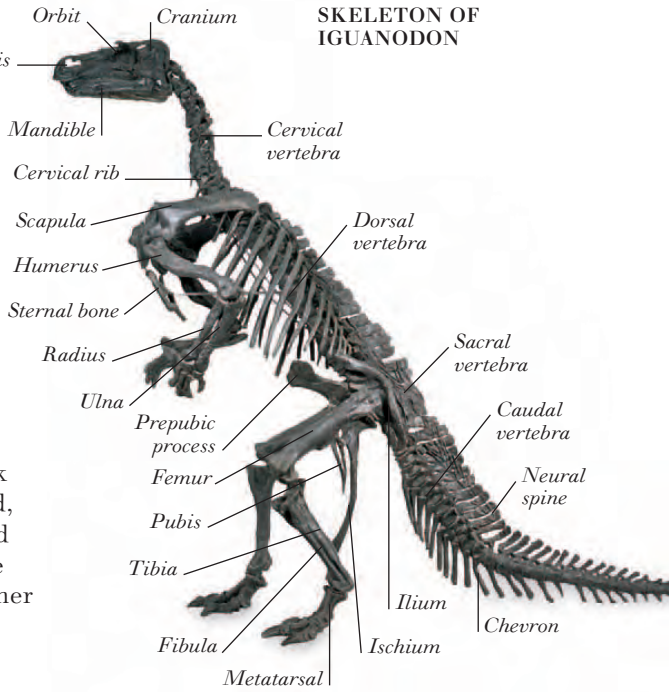
Tail club

Ornithopods 1

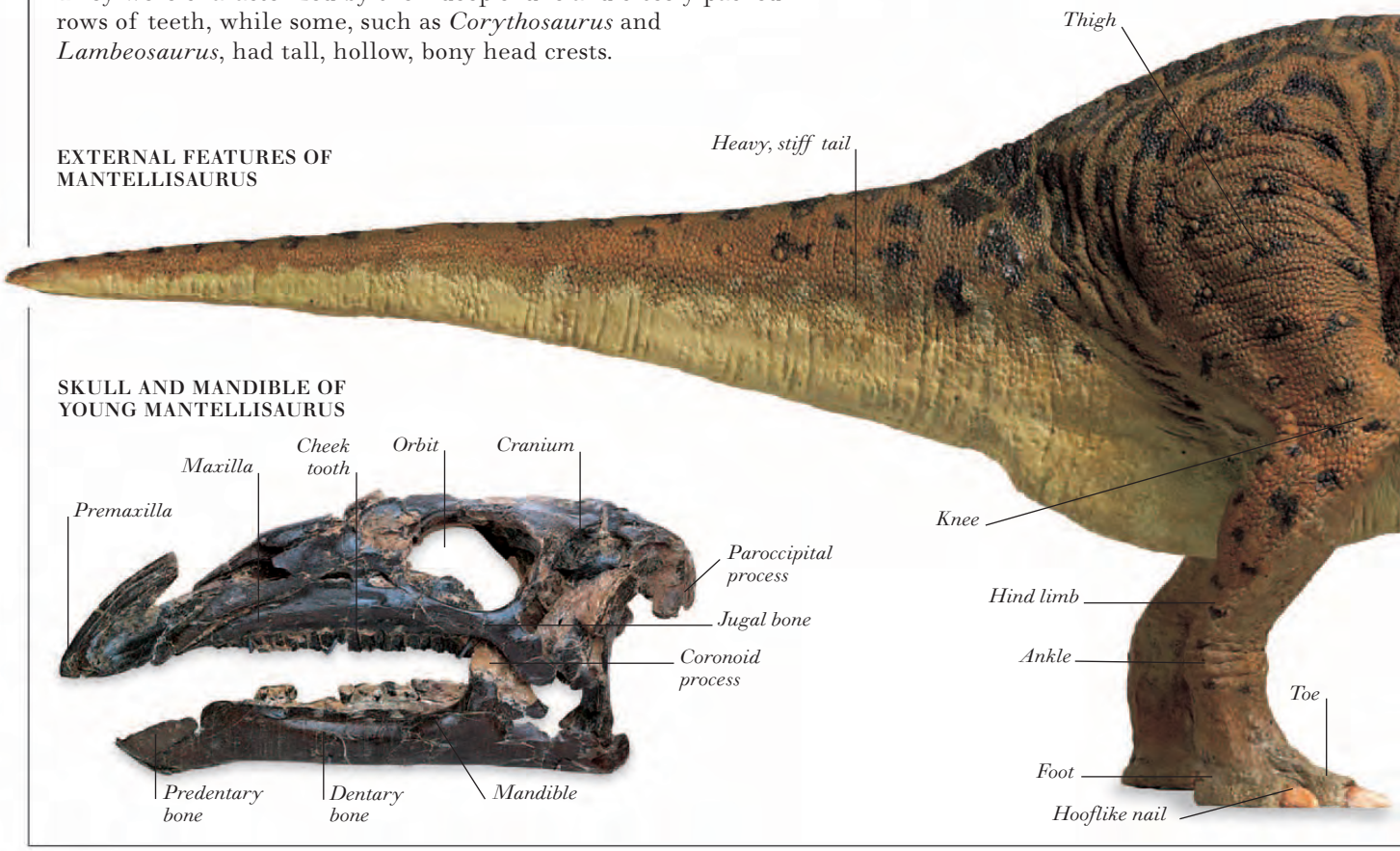
IGUANODON TOOTH

ORNITHOPODS ("BIRD FEET") were a group of ornithischian ("bird-hipped") dinosaurs. These bipedal and quadrupedal herbivores had a horny beak, plant-cutting or grinding cheek teeth, and a pelvic and tail region stiffened by bony tendons. They evolved teeth and jaws adapted to pulping vegetation and flourished from the Middle Jurassic to the Late Cretaceous period (165–65 million years ago) in North America, Europe, Africa, China, Australia, and Antarctica. Some ornithopods were no larger than a dog, while others were immense creatures up to 49 ft (15 m) long. Iguanodonts, an ornithopod group, had a broad, toothless beak at the end of a long snout, large jaws with long rows of ridged, closely packed teeth for grinding vegetation, a bulky body, and a heavy tail. *Iguanodon* and some other iguanodonts had large thumb-spikes that were strong enough to stab attackers. Another group, the hadrosaurs, such as *Gryposaurus* and *Hadrosaurus*, lived in Late Cretaceous times (97–65 million years ago) and with their broad beaks are sometimes known as "duckbills." They were characterized by their deep skulls and closely packed rows of teeth, while some, such as *Corythosaurus* and *Lambeosaurus*, had tall, hollow, bony head crests.

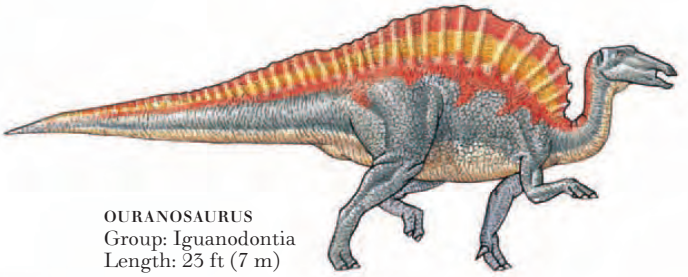
SKELETON OF IGUANODON



EXTERNAL FEATURES OF MANTELLISAURUS

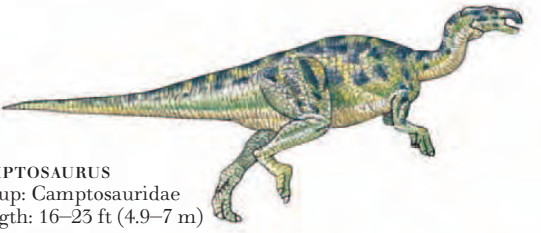


SKULL AND MANDIBLE OF YOUNG MANTELLISAURUS

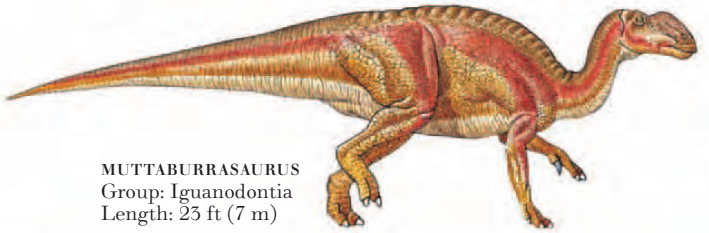


OURANOSAURUS
Group: Iguanodontia
Length: 23 ft (7 m)

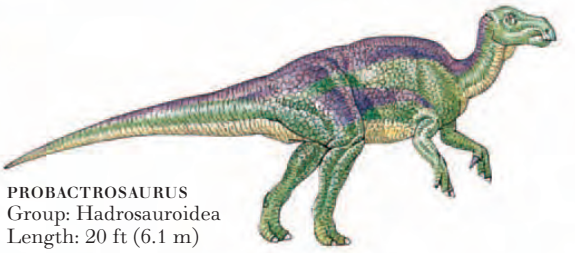
EXAMPLES OF IGUANODONTS



CAMPTOSAURUS
Group: Camptosauridae
Length: 16–23 ft (4.9–7 m)

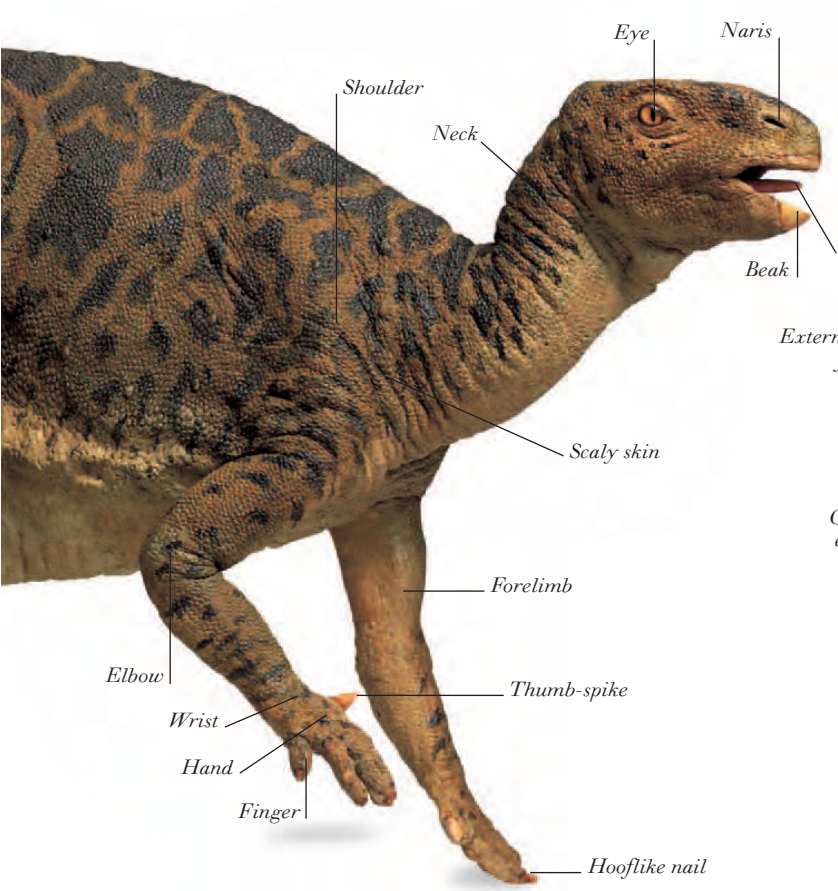


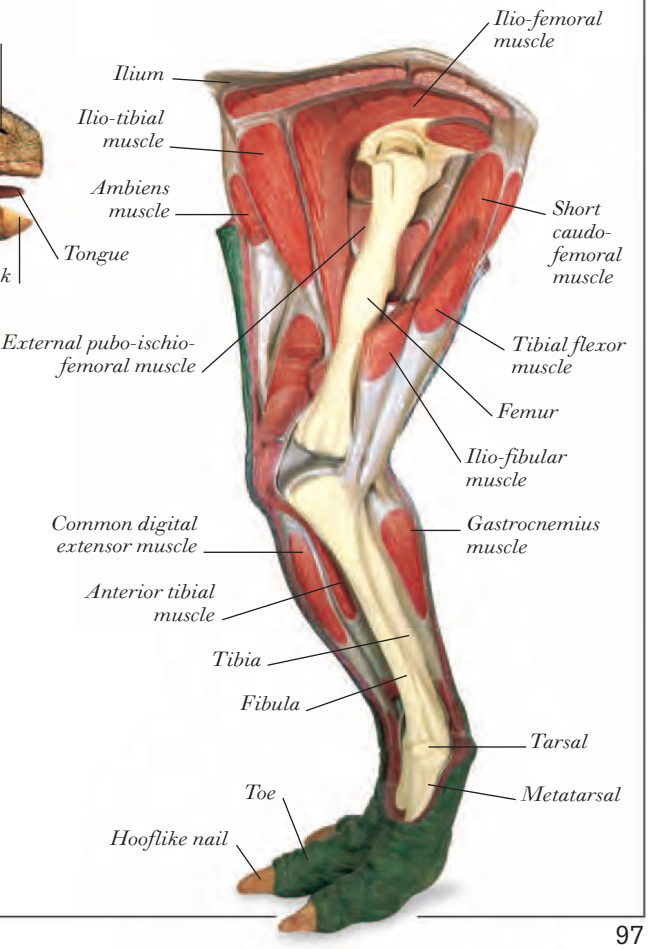
MUTTABURRASAURUS
Group: Iguanodontia
Length: 23 ft (7 m)



PROBACTROSAURUS
Group: Hadrosauroidea
Length: 20 ft (6.1 m)

INTERNAL ANATOMY OF HIND LEG OF IGUANODON





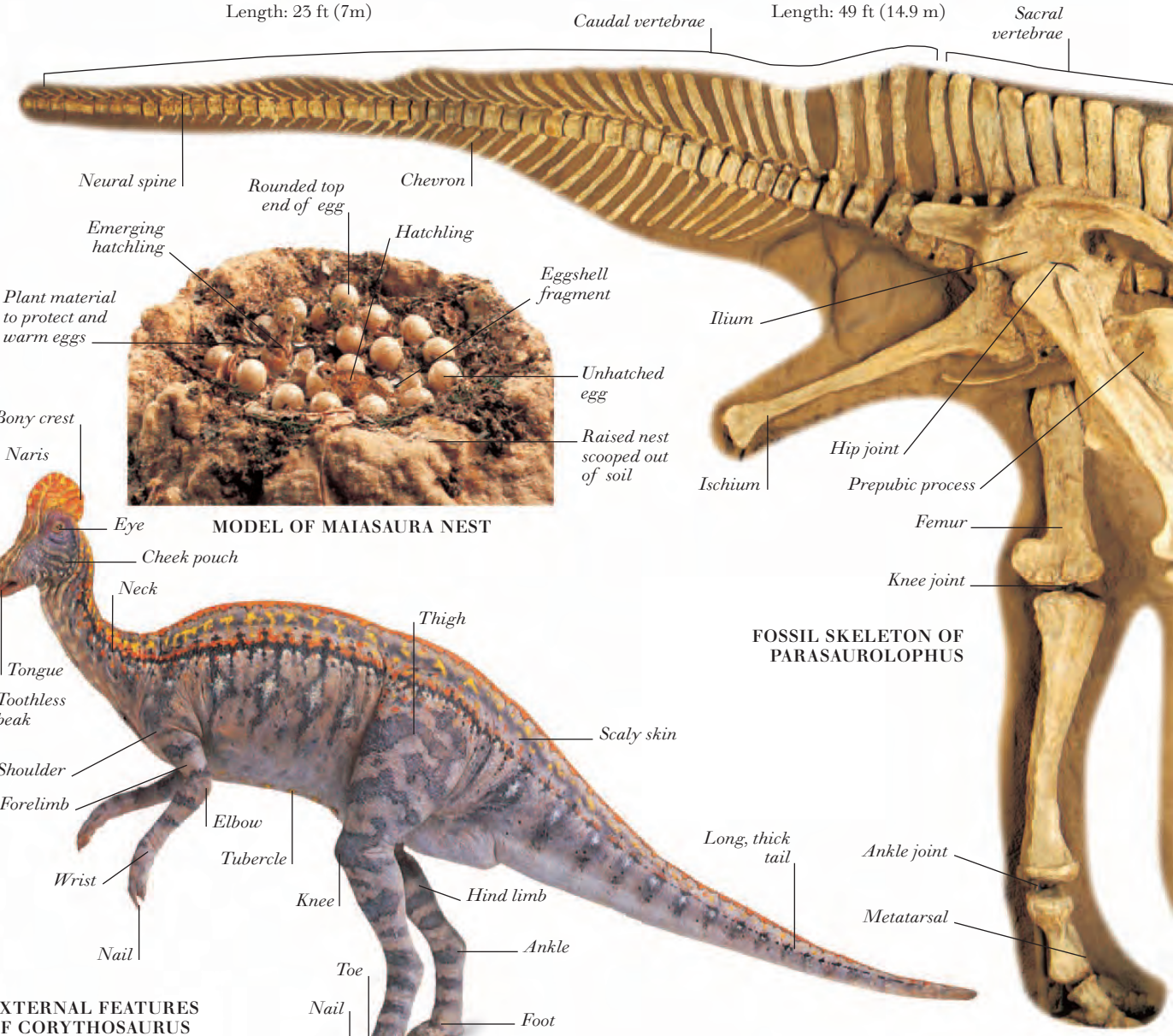
Ornithopods 2

BRACHYLOPHOSAURUS
Length: 23 ft (7m)

LAMBEOSAURUS
Length: 49 ft (14.9 m)

MODEL OF MAIASAURA NEST

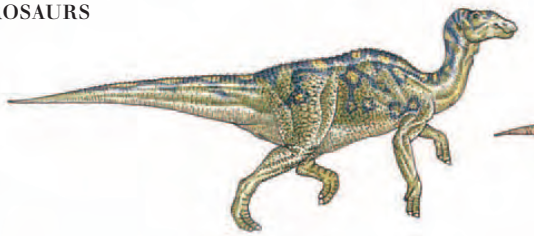
EXTERNAL FEATURES OF CORYTHOSAURUS



FOSSIL SKELETON OF PARASAUROLOPHUS

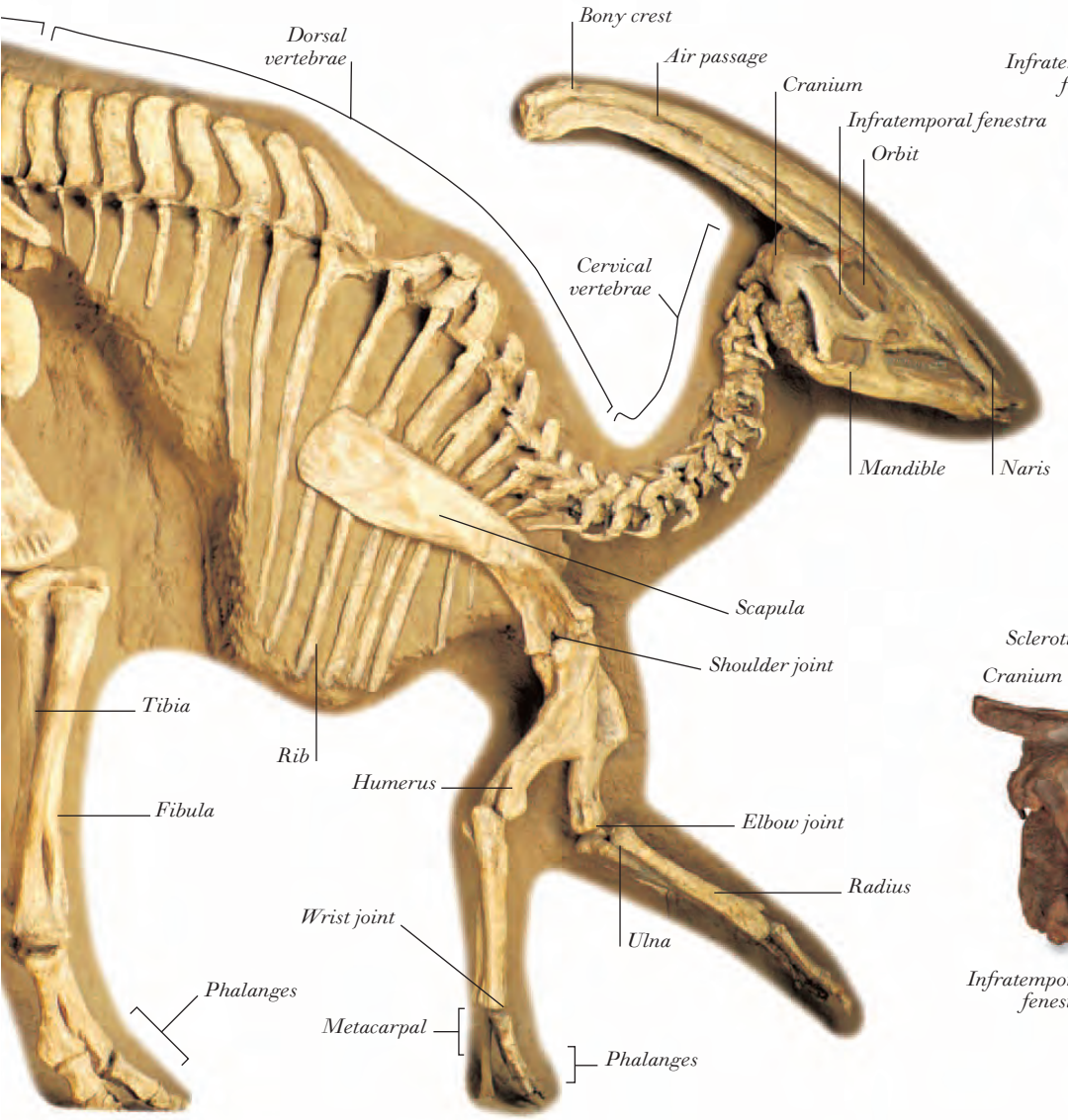
EXAMPLES OF HADROSAURS

HYPACROSAURUS
Length: 30 ft (9.1 m)

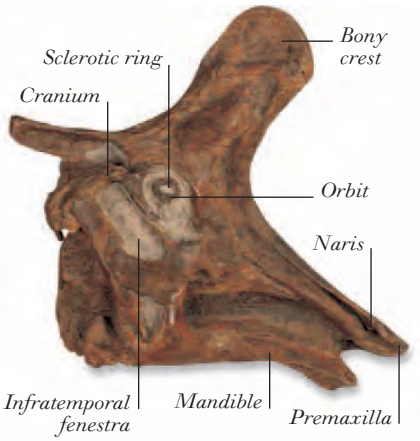


HADROSAURUS
Length: 26–33 ft (7.9–10 m)

GRYPOSAURUS
Length: 26–33 ft (7.9–10 m)



SKULL AND MANDIBLE OF JUVENILE LAMBEOSAURUS

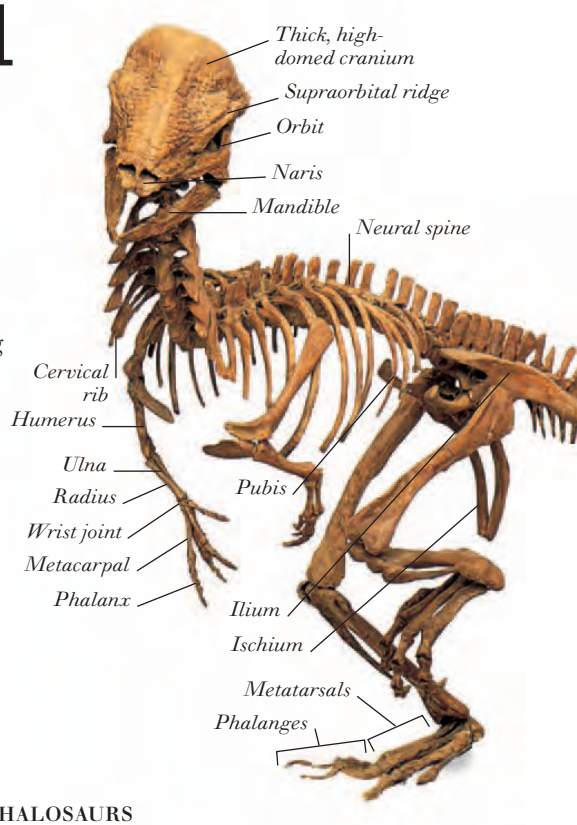


SKULL AND MANDIBLE OF ADULT LAMBEOSAURUS

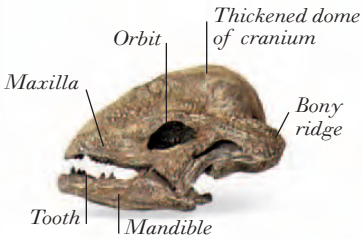
Marginocephalians 1

HEAD-BUTTING PRENOCEPHALES

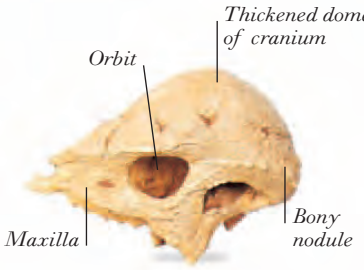
MARGINOCEPHALIA ("margined heads") were a group of bipedal and quadrupedal ornithischian dinosaurs with a narrow shelf or deep, bony frill at the back of the skull. Marginocephalians were probably descended from the same ancestor as the ornithopods and lived in what are now North America, Africa, Asia, and Europe during the Cretaceous period (145–65 million years ago). They were divided into two groups: Pachycephalosauria ("thick-headed lizards"), such as *Pachycephalosaurus* and *Stegoceras*, and Ceratopsia ("horned faces"), such as *Triceratops* and *Psittacosaurus*. The thick skulls of Pachycephalosauria may have protected their brains during possible head-butting contests fought to win territory and mates; their hips and spines may also have been strengthened to withstand the shock. The bony frill of Ceratopsia would have added to their frightening appearance when charging; the neck was strengthened for impact and to support the huge head, with its snipping beak and powerful slicing toothed jaws. A charging ceratopsian would have been a formidable opponent for even the largest predators. Ceratopsians were among the most abundant herbivorous dinosaurs of the Late Cretaceous period (97–65 million years ago).



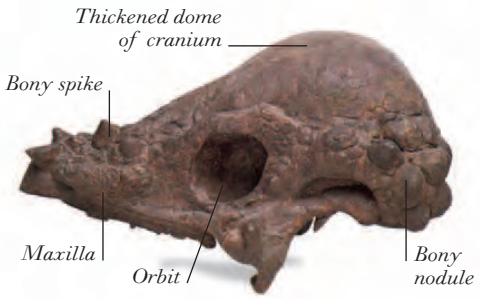
EXAMPLES OF SKULLS OF PACHYCEPHALOSAURS



SKULL AND MANDIBLE OF STEGOCERAS

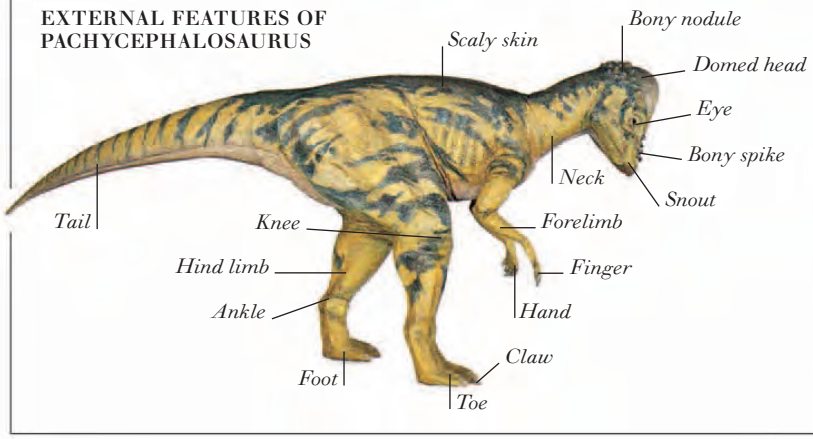


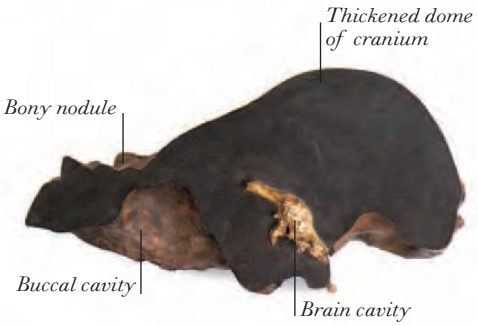
SKULL OF PRENOCEPHALE



SKULL OF PACHYCEPHALOSAURUS

EXTERNAL FEATURES OF PACHYCEPHALOSAURUS





SECTION THROUGH SKULL OF PACHYCEPHALOSAURUS

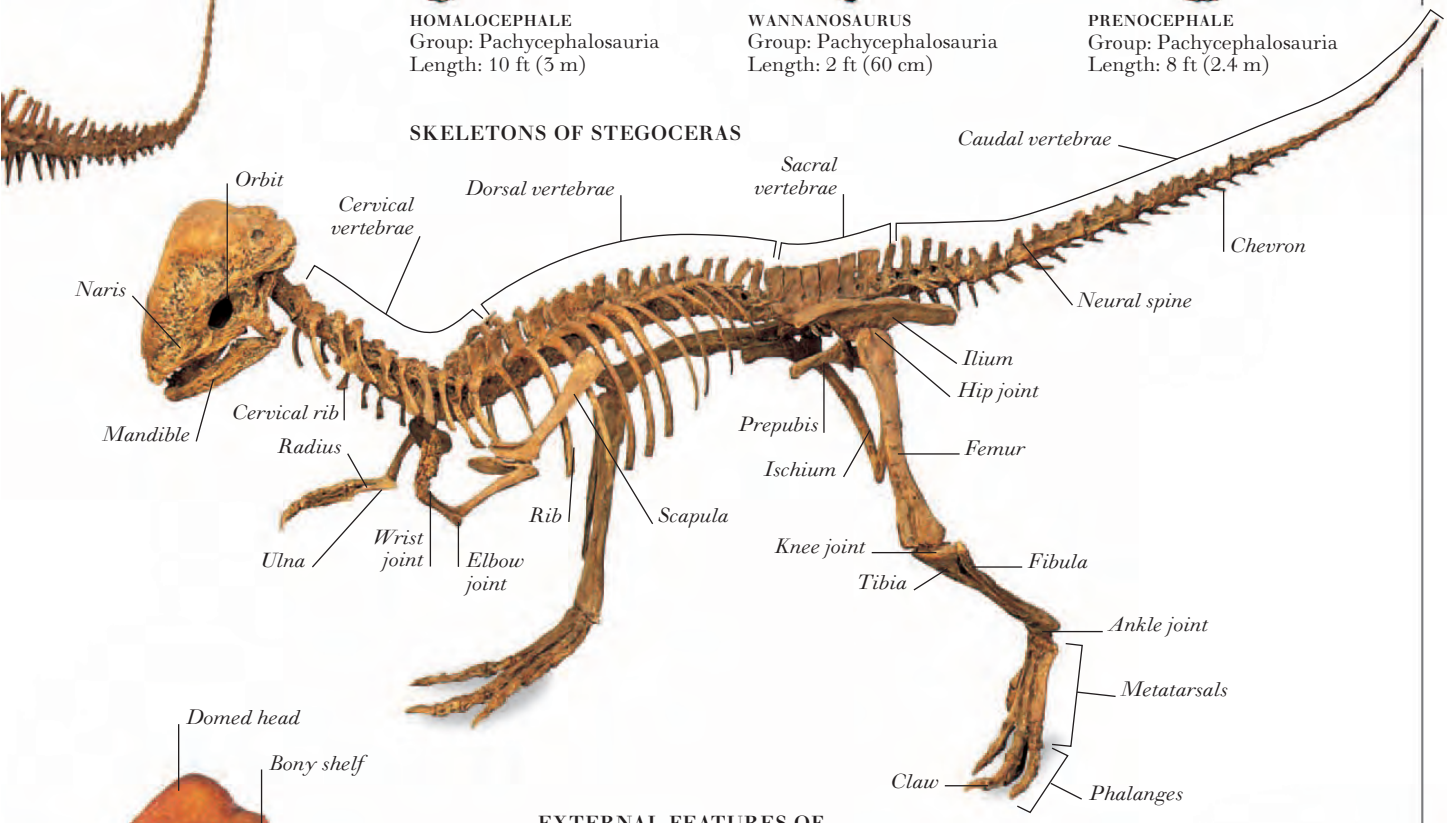
EXAMPLES OF PACHYCEPHALOSAURS

HOMALOCEPHALE
Group: Pachycephalosauria
Length: 10 ft (3 m)

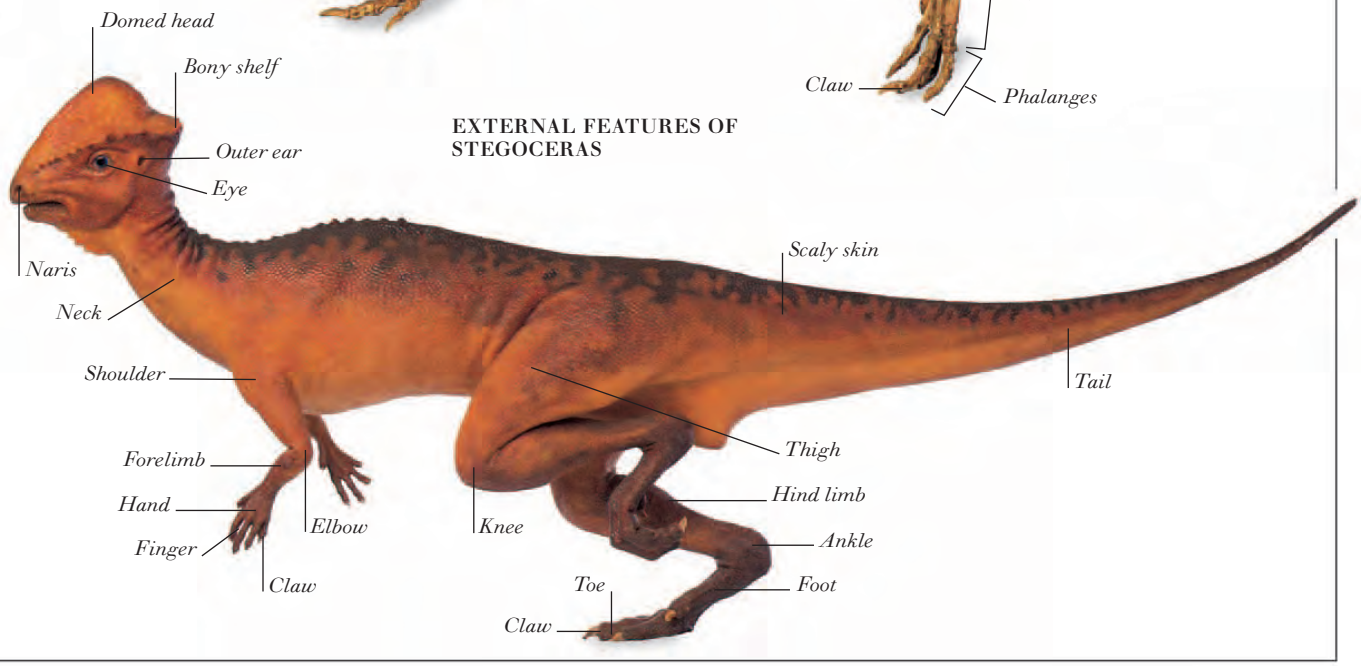
WANNANOSAURUS
Group: Pachycephalosauria
Length: 2 ft (60 cm)

PRENOCEPHALE
Group: Pachycephalosauria
Length: 8 ft (2.4 m)

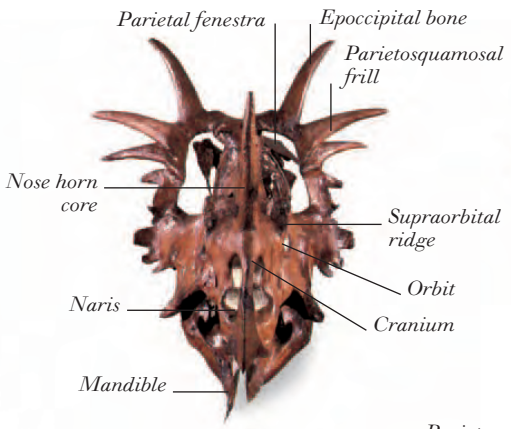
SKELETONS OF STEGOCERAS



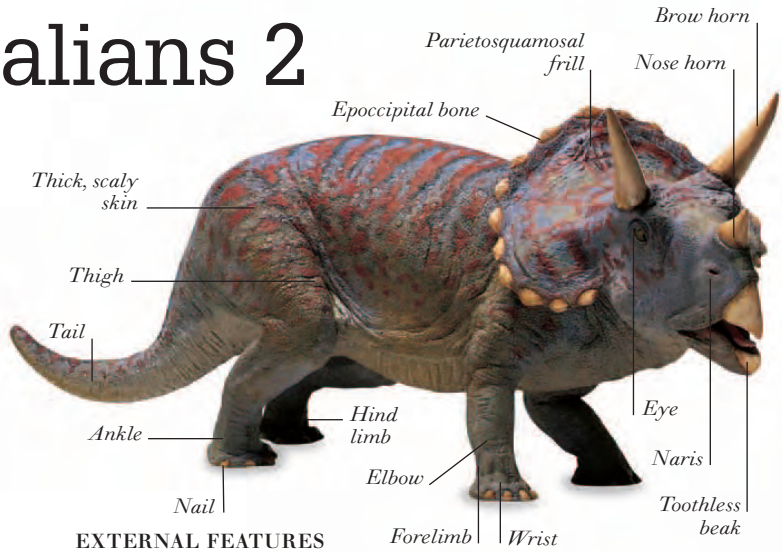
EXTERNAL FEATURES OF STEGOCERAS



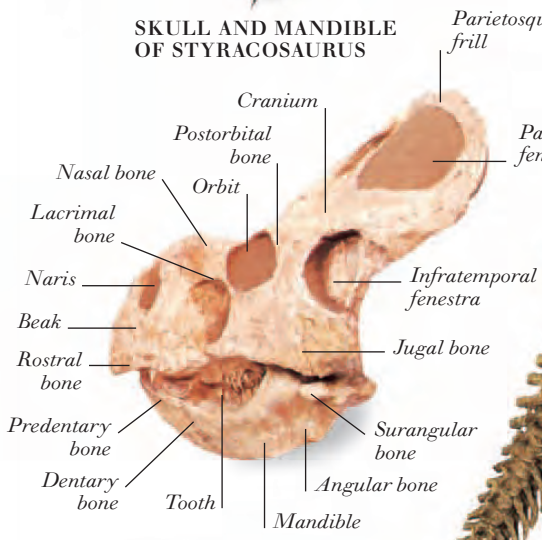
Marginocephalians 2



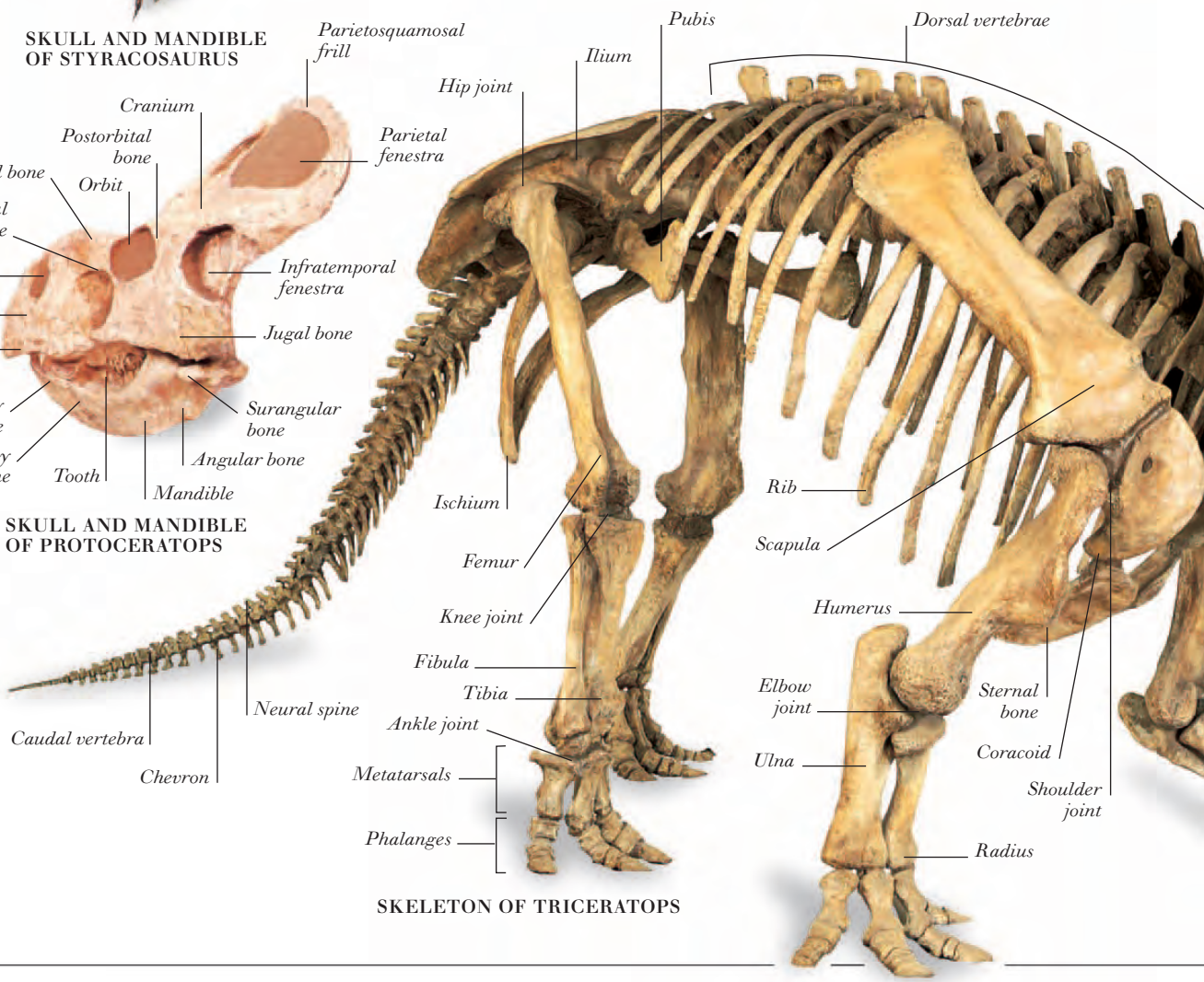
SKULL AND MANDIBLE OF STYRACOSAURUS



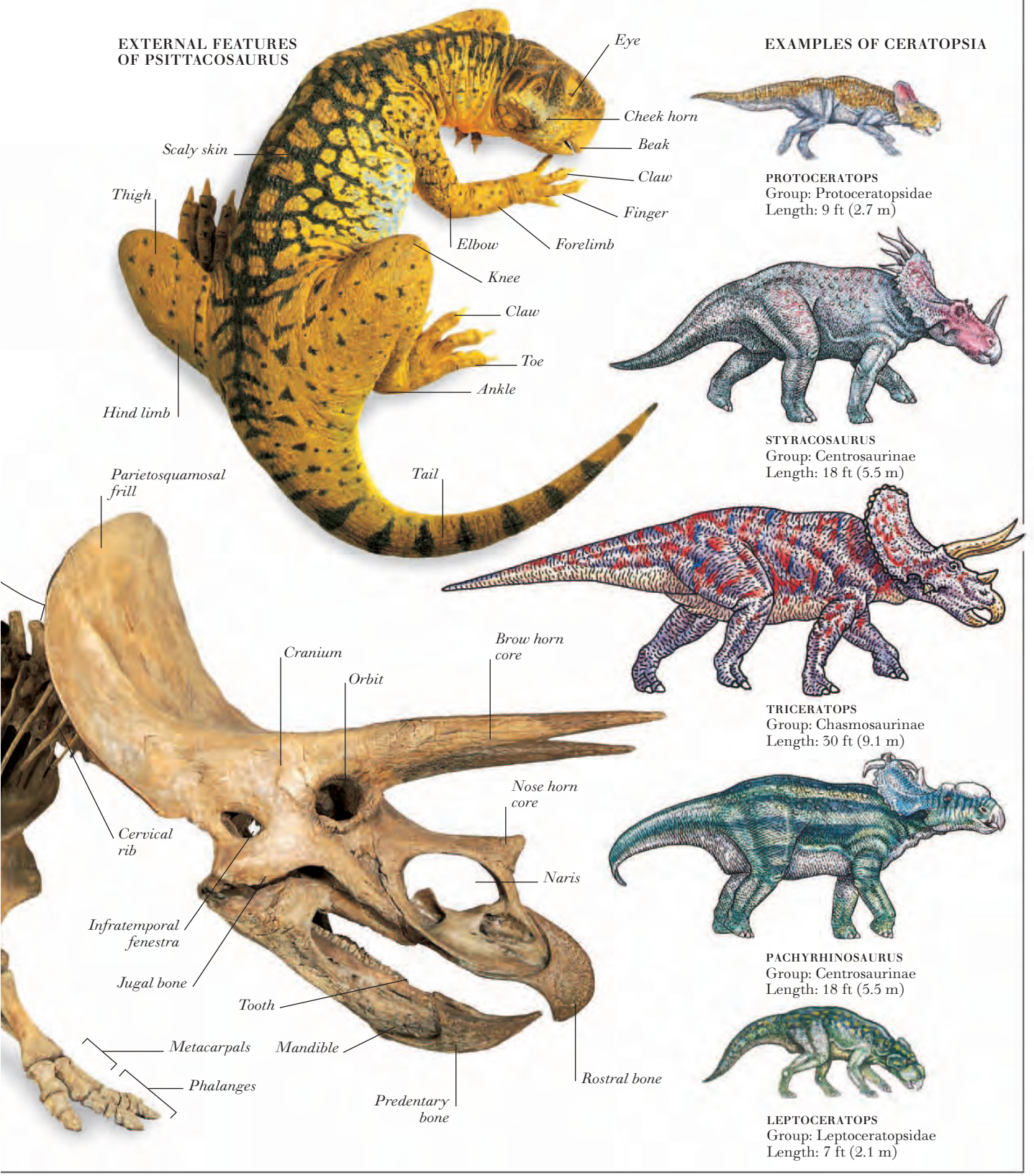
EXTERNAL FEATURES OF TRICERATOPS



SKULL AND MANDIBLE OF PROTOCERATOPS



SKELETON OF TRICERATOPS

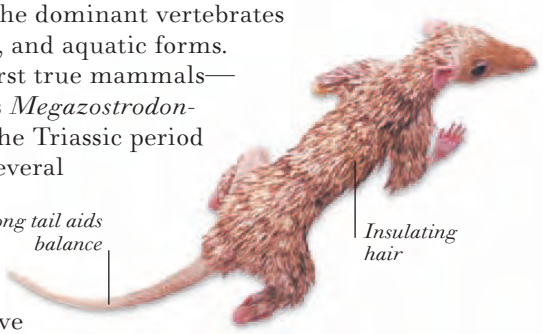

EXTERNAL FEATURES OF PSITTACOSAURUS
Eye
Cheek horn
Beak
Claw
Finger
Forelimb
Elbow
Knee
Claw
Toe
Ankle
Hind limb
Thigh
Scaly skin
Tail
Parietosquamosal frill
Cranium
Orbit
Brow horn core
Nose horn core
Naris
Cervical rib
Infratemporal fenestra
Jugal bone
Tooth
Metacarpals
Phalanges
Mandible
Predentary bone
Rostral bone
EXAMPLES OF CERATOPSIA
PROTOCERATOPS
Group: Protoceratopsidae
Length: 9 ft (2.7 m)
STYRACOSAURUS
Group: Centrosaurinae
Length: 18 ft (5.5 m)
TRICERATOPS
Group: Chasmosaurinae
Length: 30 ft (9.1 m)
PACHYRHINOSAURUS
Group: Centrosaurinae
Length: 18 ft (5.5 m)
LEPTOCERATOPS
Group: Leptoceratopsidae
Length: 7 ft (2.1 m)

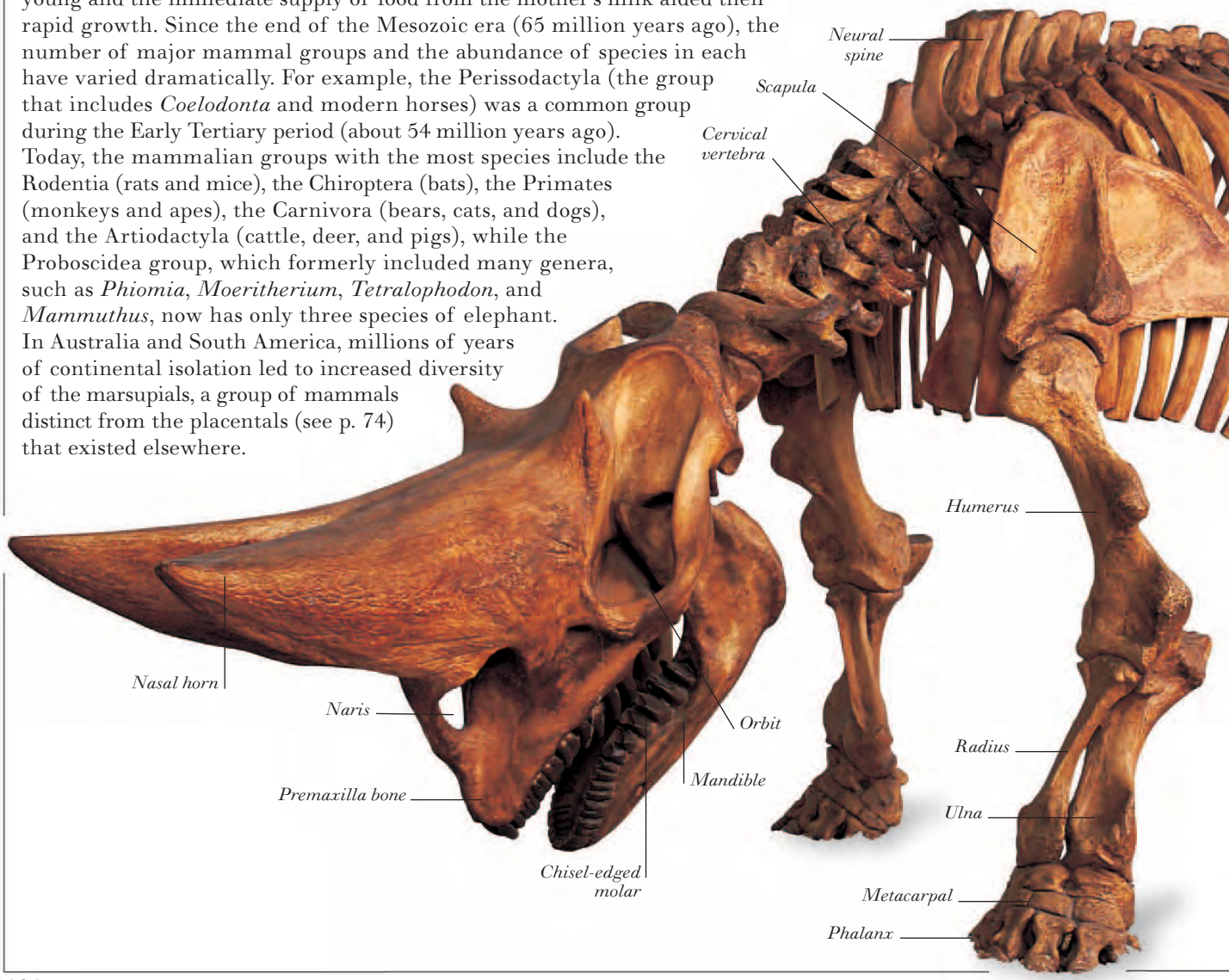
Mammals 1

TETRALOPHODON CHEEK TEETH

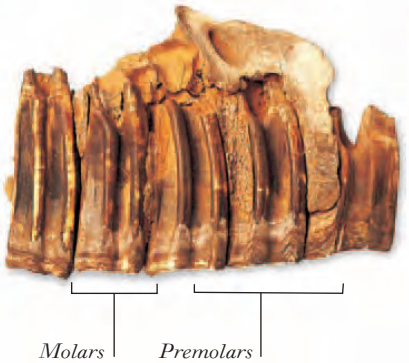
SINCE THE EXTINCTION of most of the dinosaurs 65 million years ago, mammals (along with birds) have been the dominant vertebrates on land. This class includes terrestrial, aerial, and aquatic forms. Having developed from the therapsids, the first true mammals—small, nocturnal, shrewlike creatures, such as *Megazostrodon*-appeared over 200 million years ago during the Triassic period (250–200 million years ago). Mammals had several features that differed from those of their ancestors: an efficient four-chambered heart allowed these warm-blooded animals to sustain high levels of activity; a covering of hair helped them maintain a constant body temperature; an improved limb structure gave them more efficient locomotion; and the birth of live young and the immediate supply of food from the mother's milk aided their rapid growth. Since the end of the Mesozoic era (65 million years ago), the number of major mammal groups and the abundance of species in each have varied dramatically. For example, the Perissodactyla (the group that includes *Coelodonta* and modern horses) was a common group during the Early Tertiary period (about 54 million years ago). Today, the mammalian groups with the most species include the Rodentia (rats and mice), the Chiroptera (bats), the Primates (monkeys and apes), the Carnivora (bears, cats, and dogs), and the Artiodactyla (cattle, deer, and pigs), while the Proboscidea group, which formerly included many genera, such as *Phiomia*, *Moeritherium*, *Tetralophodon*, and *Mammuthus*, now has only three species of elephant. In Australia and South America, millions of years of continental isolation led to increased diversity of the marsupials, a group of mammals distinct from the placentals (see p. 74) that existed elsewhere.

MODEL OF A MEGAZOSTRODON

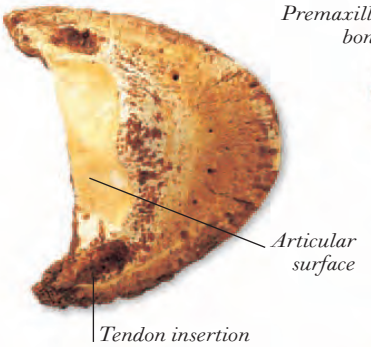


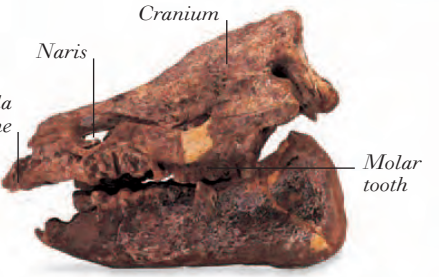


UPPER JAWBONE (MAXILLA) OF A HORSE

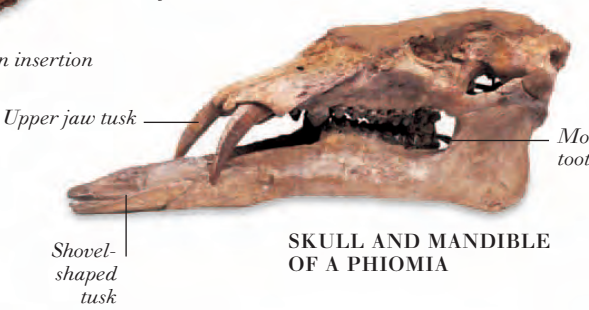


HOOFBONE (THIRD PHALANX) OF A HORSE

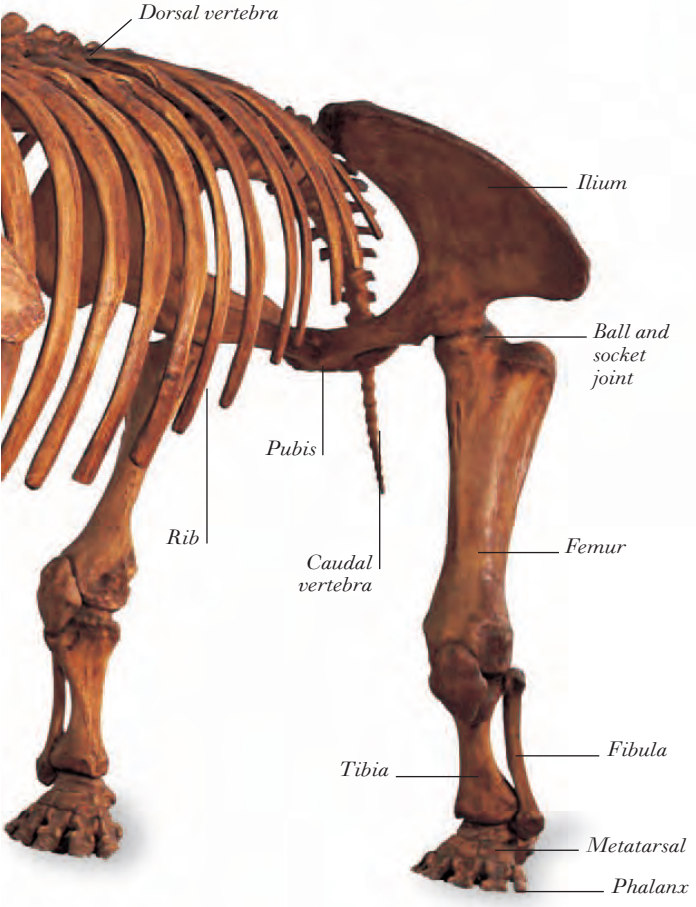




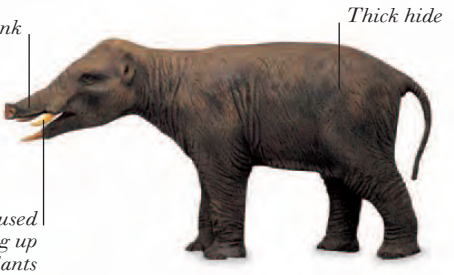
SKULL AND MANDIBLE OF A MOERITHERIUM



SKULL AND MANDIBLE OF A PHIOMIA



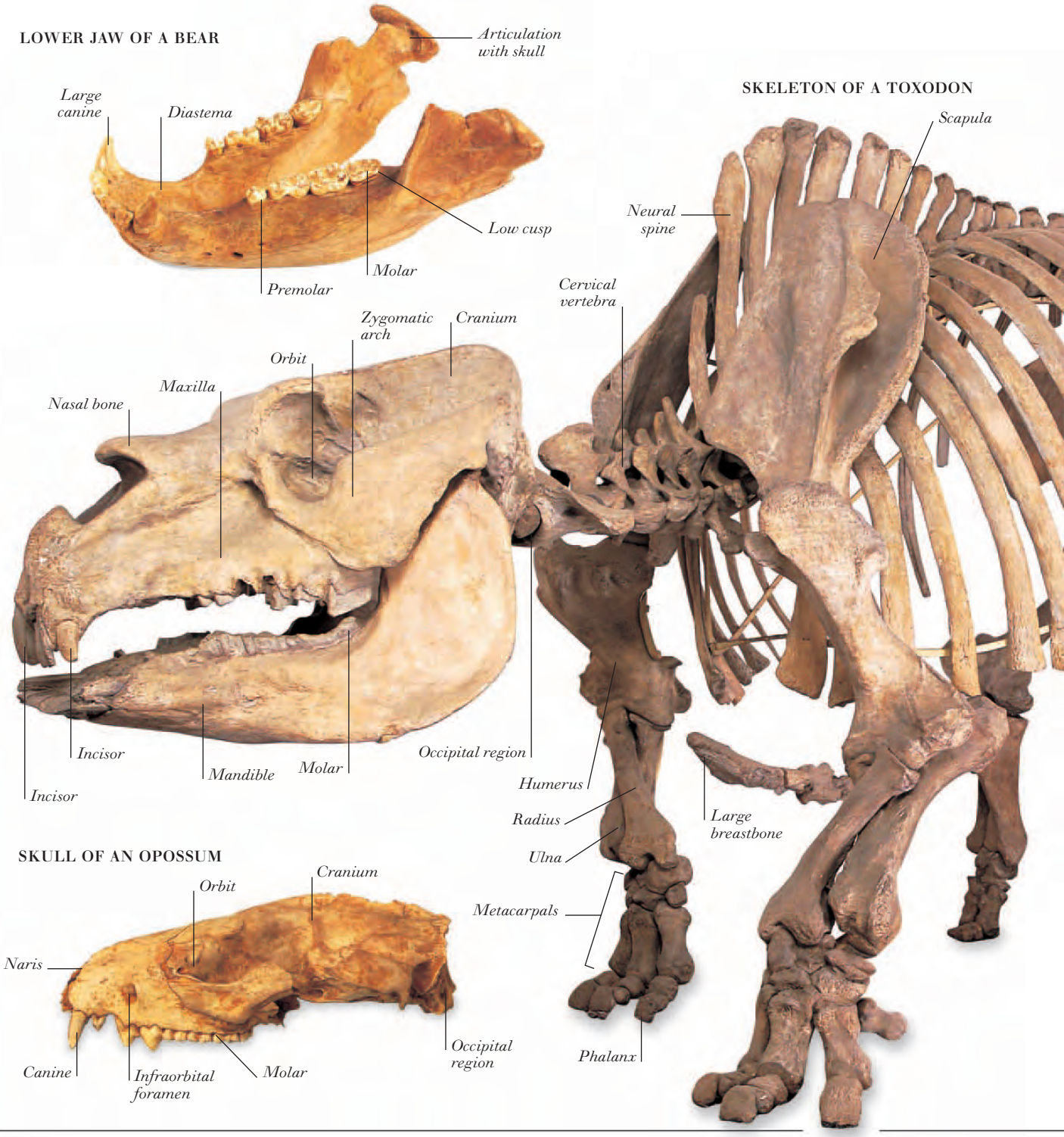
SKELETON OF AN ARSINOITHERIUM



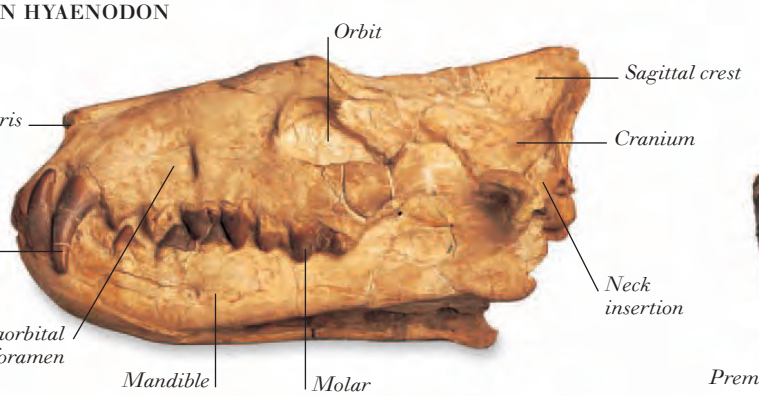
MODEL OF A PHIOMIA

FOSSIL SKELETON OF A BAT

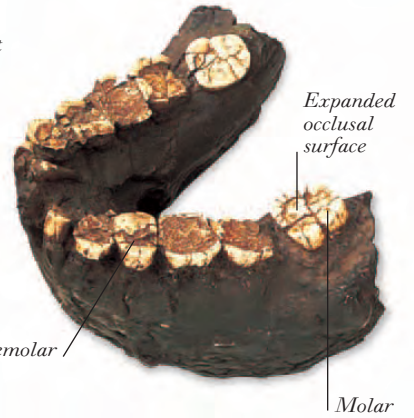
Mammals 2

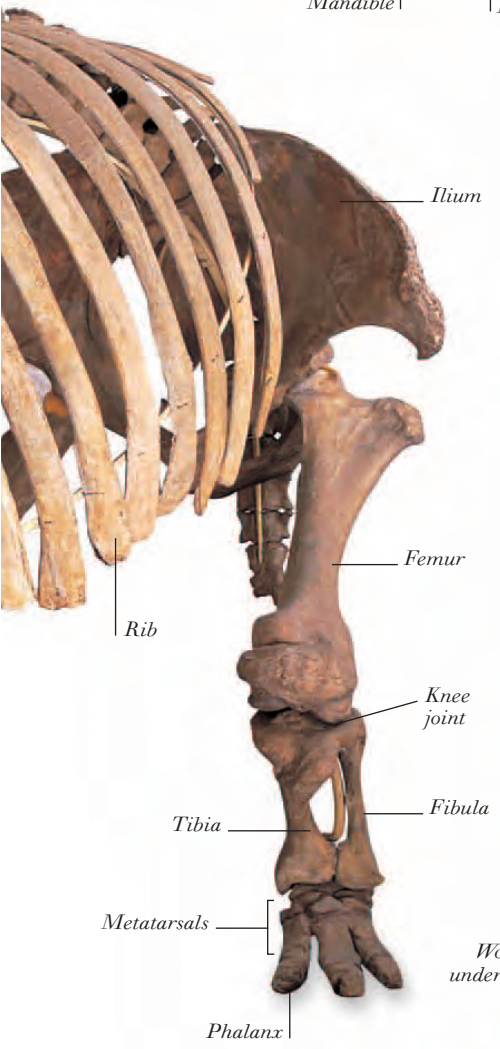

LOWER JAW OF A BEAR
Articulation with skull
Large canine
Diastema
Low cusp
Molar
Premolar
SKELETON OF A TOXODON
Scapula
Neural spine
Cervical vertebra
Zygomatic arch
Cranium
Orbit
Maxilla
Nasal bone
Incisor
Incisor
Mandible
Molar
Occipital region
Humerus
Radius
Ulna
Metacarpals
Large breastbone
Phalanx
SKULL OF AN OPOSSUM
Cranium
Orbit
Naris
Canine
Infraorbital foramen
Molar
Occipital region

FOSSIL SKULL OF AN HYAENODON

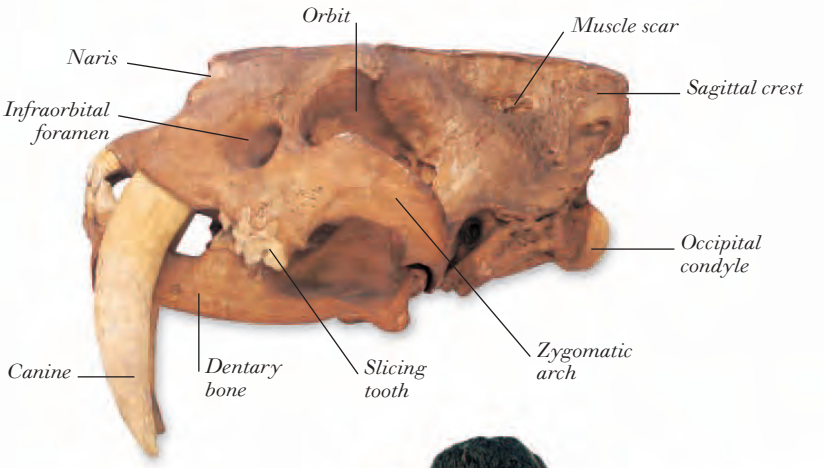


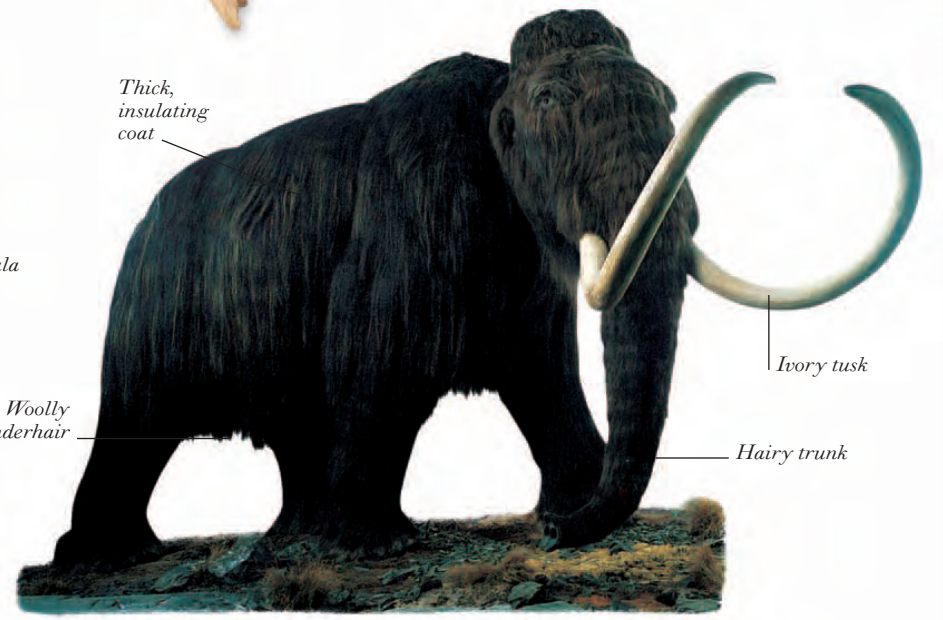
LOWER JAW OF AN AUSTRALOPITHECUS





SKULL OF A SMILODON

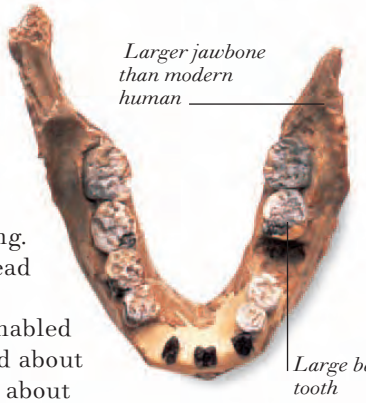




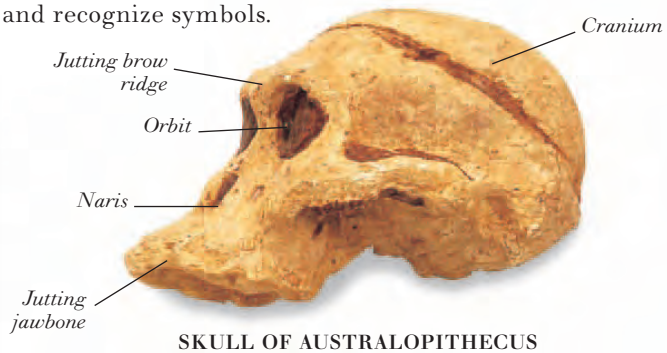
RECONSTRUCTION OF A MAMMOTH

The first humans

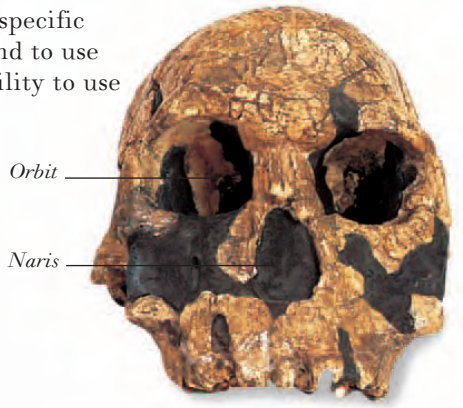
MODERN HUMANS BELONG TO THE MAMMALIAN order of primates (see pp. 202–203), which originated about 55 million years ago; primates included the only extant hominid species. The earliest hominid was *Ardipithecus* ("ground ape") and *Australopithecus* ("southern ape"), both small-brained intermediates between apes and humans that were capable of standing and walking upright. *Homo habilis*, the earliest member of the genus Homo, appeared at least 2 million years ago. This larger-brained "handy man" began making tools for hunting. *Homo ergaster* first appeared in Africa about 1.8 million years ago and spread into Asia about 800,000 years later. Smaller-toothed than *Homo habilis*, H. ergaster—followed by Homo erectus—developed fire as a tool, which enabled it to cook food. Neanderthals, a near relative of modern humans, originated about 200,000 years ago, and *Homo sapiens* (modern humans) appeared in Africa about 100,000 years later. The two coexisted for thousands of years, but by 30,000 years ago, *Homo sapiens* had become dominant and the Neanderthals had died out. Classification of *Homo sapiens* in relation to its ancestors is enormously problematic: modern humans must be classified not only by bone structure, but also by specific behavior—the ability to plan future action; to follow traditions; and to use symbolic communication, including complex language and the ability to use and recognize symbols.



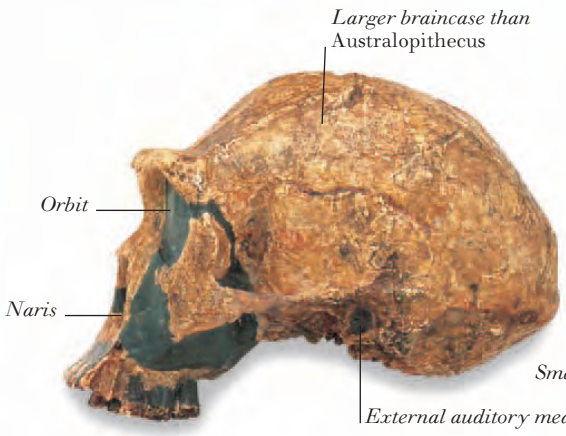
JAWBONE OF AUSTRALOPITHECUS (SOUTHERN APE)



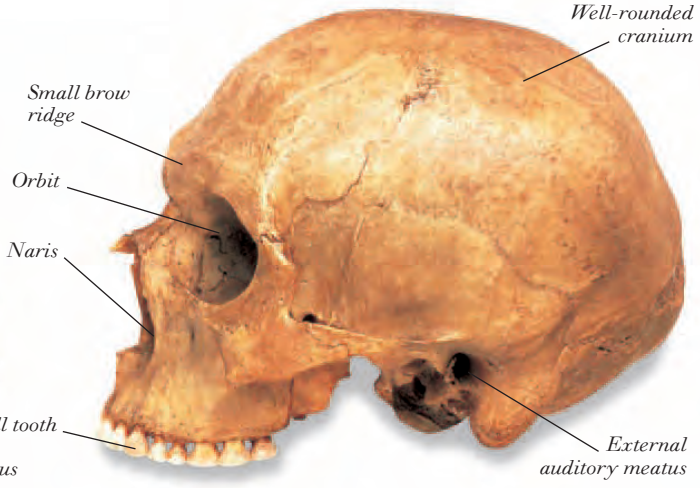
SKULL OF AUSTRALOPITHECUS (SOUTHERN APE)



SKULL OF HOMO HABILIS (FIRST MEMBER OF HOMO GENUS)



SKULL OF HOMO ERECTUS (UPRIGHT MAN)



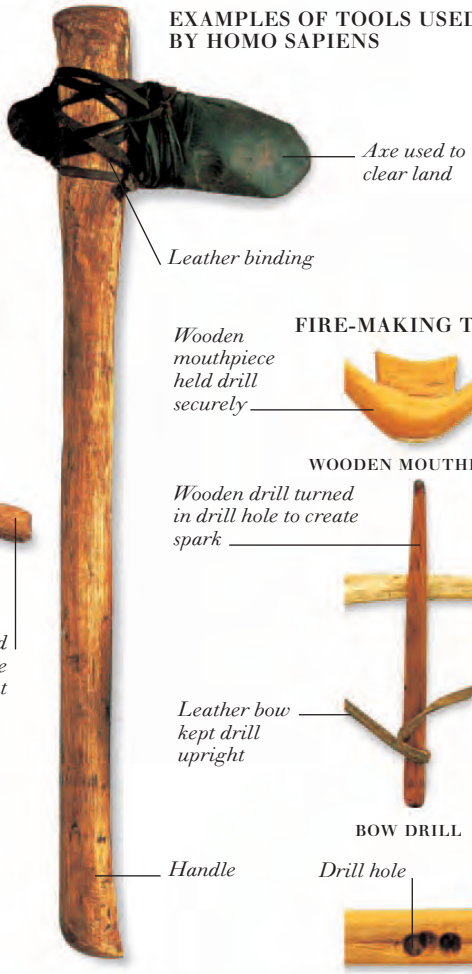
SKULL OF HOMO SAPIENS (MODERN HUMAN)

FLINT TOOL MADE ABOUT 250,000 YEARS AGO

FLINT HANDAXE

FLINT FLAKE

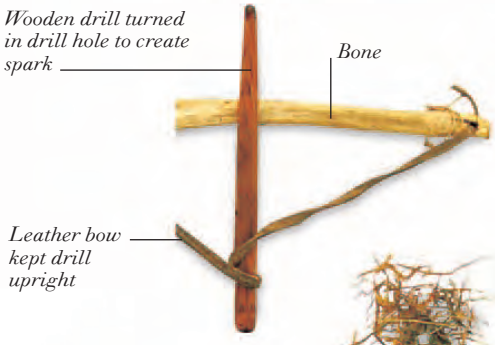
EXAMPLES OF TOOLS USED BY HOMO SAPIENS



FARMING AX

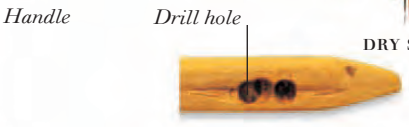
FIRE-MAKING TOOLS

WOODEN MOUTHPIECE

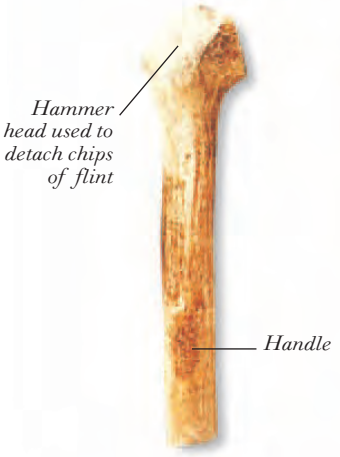


BOW DRILL

DRY STRAW



WOODEN HEARTH

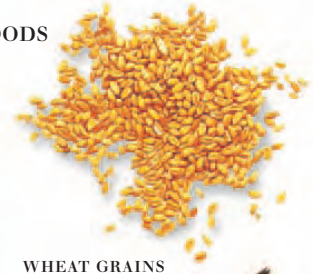


ANTLER HAMMER

RED DEER ANTLER HAMMER

EXAMPLES OF PREHISTORIC FOODS

MINT



WHEAT GRAINS

SALMON

SPEAR AND ARROW HEADS

HARPOON POINT

FISHING TACKLE

WOODEN ARROW

FLINT ARROW

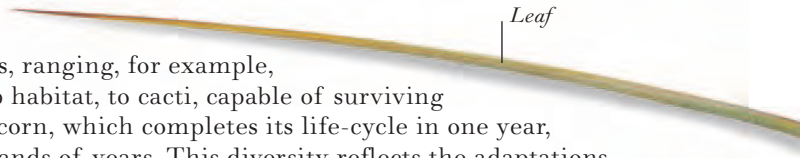
Plants

Plant Varieties 112
Fungi and Lichens 114
Algae and Seaweeds 116
Liverworts and Mosses 118
Horsetails, Clubmosses, and Ferns 120
Gymnosperms 1 122
Gymnosperms 2 124
Monocotyledons and Dicotyledons 126
Herbaceous Flowering Plants 128
Woody Flowering Plants 130
Roots 132
Stems 134
Leaves 136
Photosynthesis 138
Flowers 1 140
Flowers 2 142
Pollination 144
Fertilization 146
Succulent Fruits 148
Dry Fruits 150
Germination 152
Vegetative Reproduction 154
Dryland Plants 156
Wetland Plants 158
Carnivorous Plants 160
Epiphytic and Parasitic Plants 162

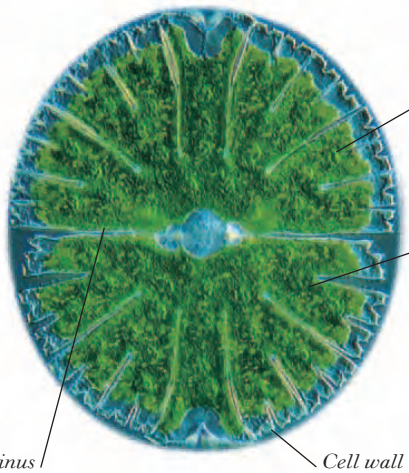
Plant varieties

THERE ARE MORE THAN 300,000 SPECIES of plant. They show a wide diversity of forms and life-styles, ranging, for example, from delicate liverworts, adapted for life in a damp habitat, to cacti, capable of surviving in the desert, and from herbaceous plants, such as corn, which completes its life-cycle in one year, to the giant redwood tree, which can live for thousands of years. This diversity reflects the adaptations of plants to survive in a wide range of habitats. This is seen most clearly in the flowering plants (phylum Angiospermophyta), which are the most numerous, with over 250,000 species, and the most widespread, being found from the tropics to the poles. Despite their diversity, plants share certain characteristics: typically, plants are green, and make their food by photosynthesis; and most plants live in or on a substrate, such as soil, and do not actively move. Algae (kingdom Protista) and fungi (kingdom Fungi) have some plantlike characteristics and are often studied alongside plants, although they are not true plants.

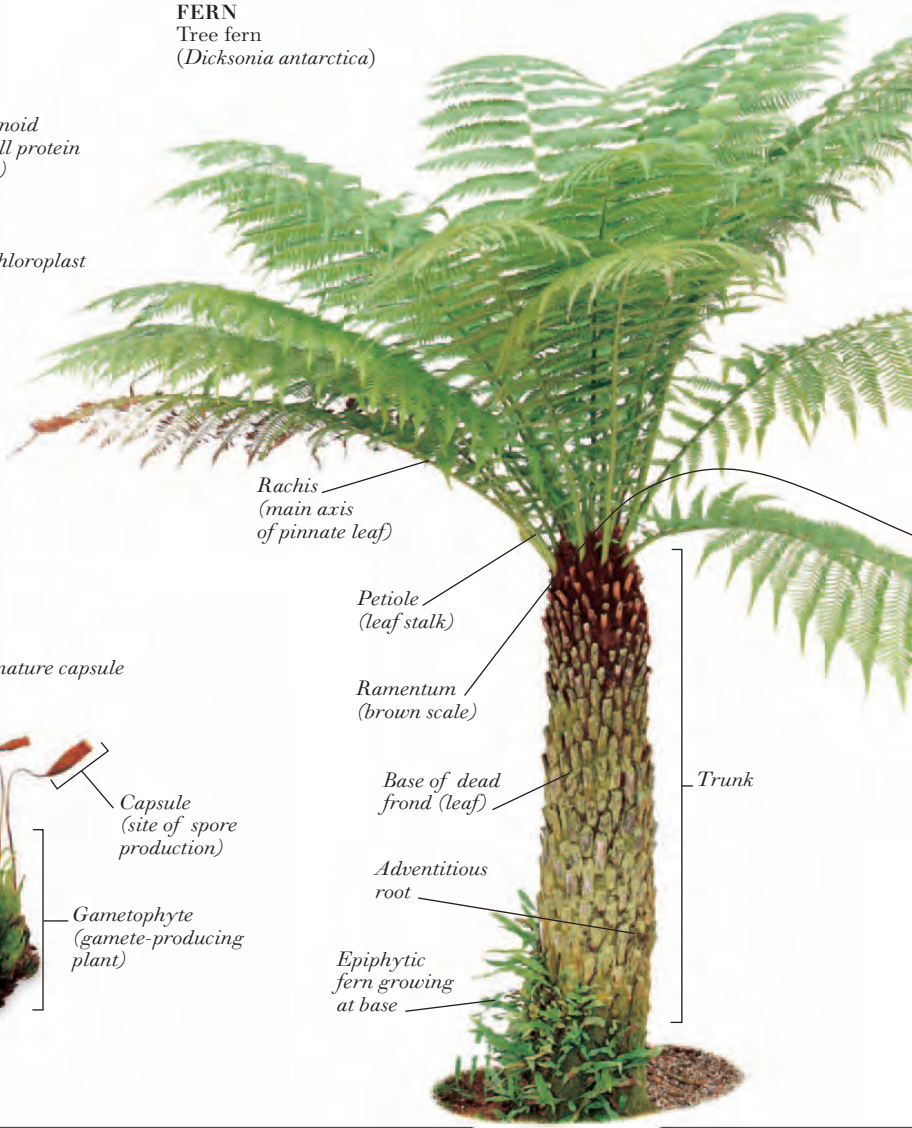
FLOWERING PLANT
Bromeliad
(*Acanthostachys strobilacea*)



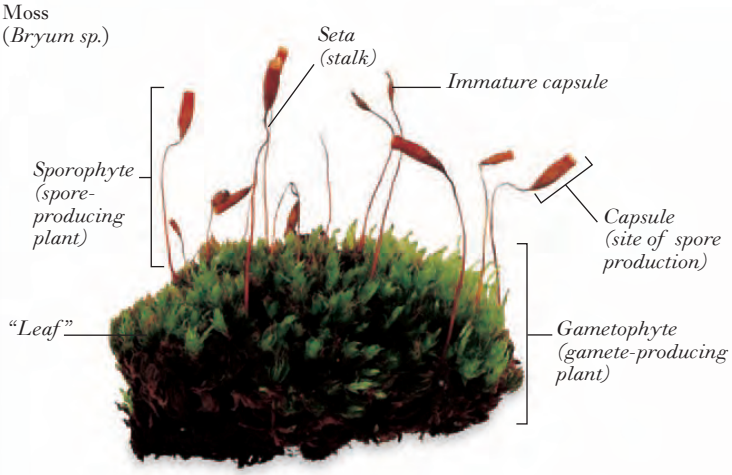
GREEN ALGA
Micrograph of desmid
(*Micrasterias sp.*)

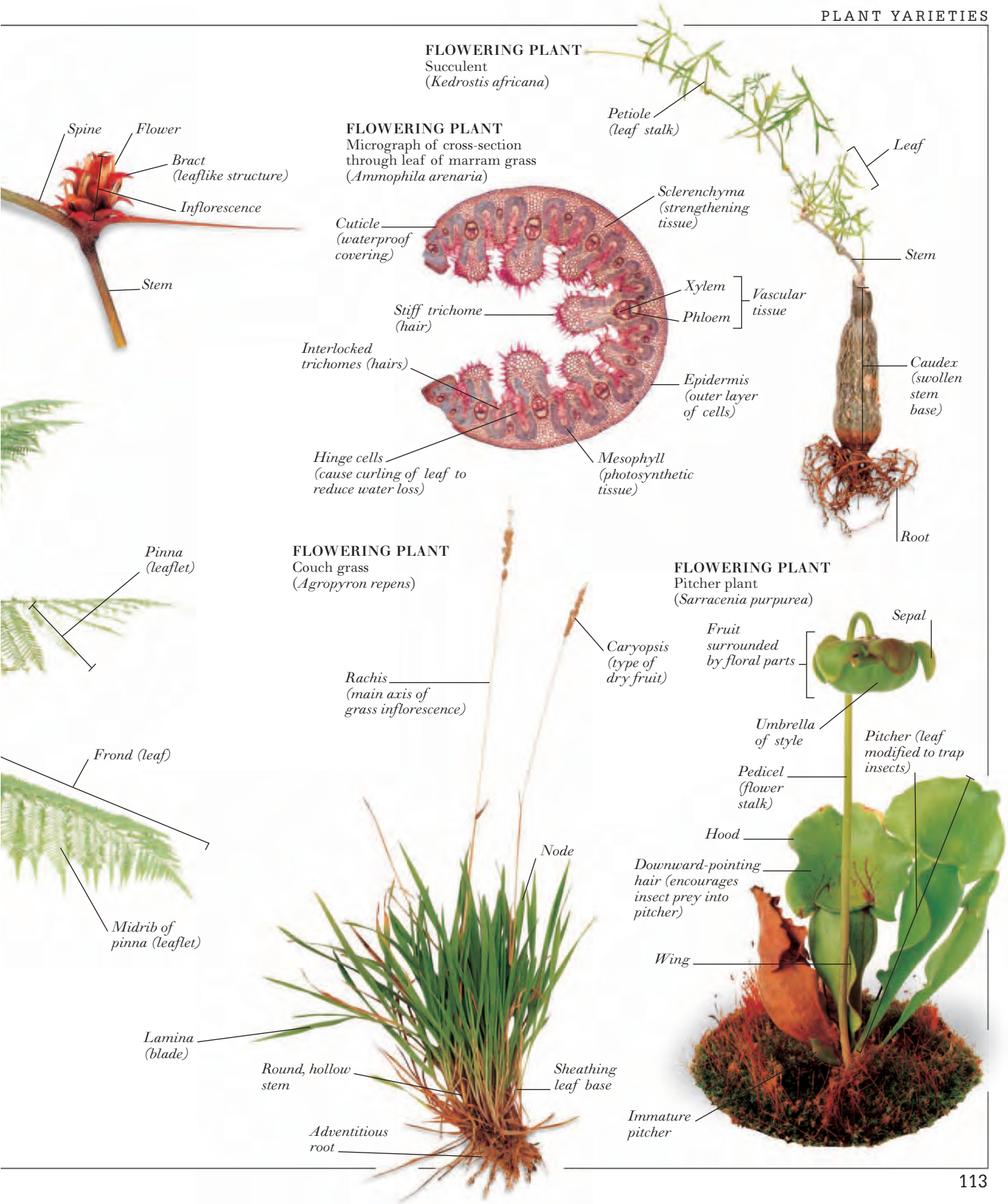


FERN
Tree fern
(*Dicksonia antarctica*)



BRYOPHYTE
Moss
(*Bryum sp.*)

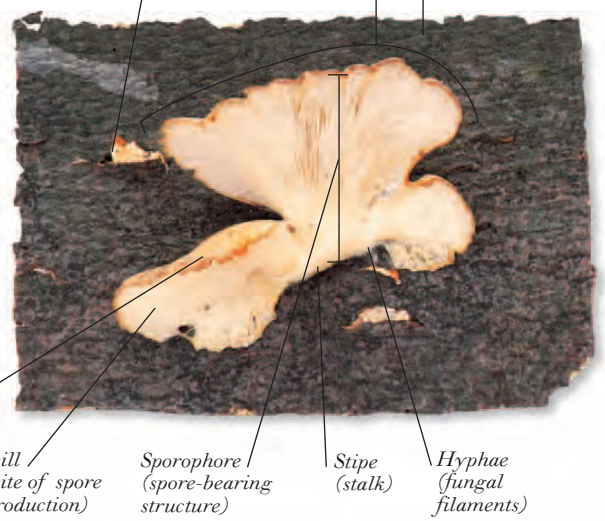



FLOWERING PLANT
Succulent
(Kedrostis africana)
Petiole
(leaf stalk)
Leaf
Stem
Caudex
(swollen
stem
base)
Root
Spine
Flower
Bract
(leaflike structure)
Inflorescence
Stem
FLOWERING PLANT
Micrograph of cross-section
through leaf of marram grass
(Ammophila arenaria)
Cuticle
(waterproof
covering)
Sclerenchyma
(strengthening
tissue)
Xylem
Phloem
Vascular
tissue
Stiff trichome
(hair)
Interlocked
trichomes (hairs)
Epidermis
(outer layer
of cells)
Hinge cells
(cause curling of leaf to
reduce water loss)
Mesophyll
(photosynthetic
tissue)
Pinna
(leaflet)
FLOWERING PLANT
Couch grass
(Agropyron repens)
Caryopsis
(type of
dry fruit)
Rachis
(main axis of
grass inflorescence)
FLOWERING PLANT
Pitcher plant
(Sarracenia purpurea)
Sepal
Fruit
surrounded
by floral parts
Umbrella
of style
Pitcher (leaf
modified to trap
insects)
Pedicel
(flower
stalk)
Hood
Downward-pointing
hair (encourages
insect prey into
pitcher)
Wing
Frond (leaf)
Midrib of
pinna (leaflet)
Node
Lamina
(blade)
Round, hollow
stem
Sheathing
leaf base
Adventitious
root
Immature
pitcher

Fungi and lichens

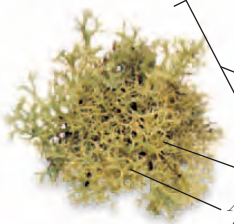
FUNGI WERE ONCE THOUGHT OF AS PLANTS but are now classified as a separate kingdom. This kingdom includes not only the familiar mushrooms, puffballs, stinkhorns, and molds, but also yeasts, smuts, rusts, and lichens. Most fungi are multicellular, consisting of a mass of threadlike hyphae that together form a mycelium. However, the simpler fungi (e.g., yeasts) are microscopic, single-celled organisms. Typically, fungi reproduce by means of spores. Most fungi feed on dead or decaying matter, or on living organisms. A few fungi obtain their food from plants or algae, with which they have a symbiotic (mutually advantageous) relationship. Lichens are a symbiotic partnership between algae and fungi. Of the six types of lichens, the three most common are crustose (flat and crusty), foliose (leafy), and fruticose (shrublike). Some lichens (e.g., *Cladonia floerkeana*) are a combination of types. Lichens reproduce by means of spores or soredia (powdery vegetative fragments).

EXAMPLES OF FUNGI

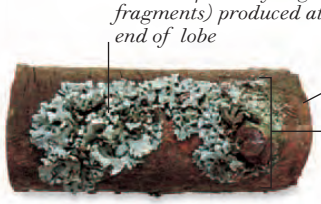


OYSTER FUNGUS
(*Pleurotus pulmonarius*)

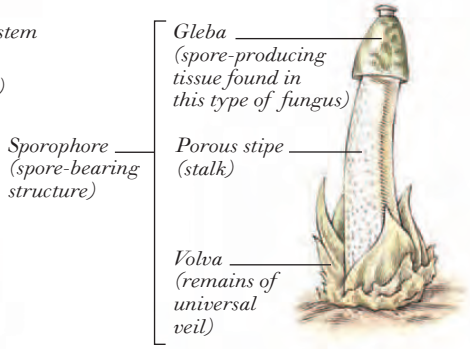
EXAMPLES OF LICHENS



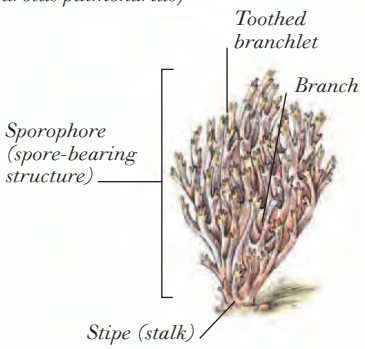
FRUTICOSE
Cladonia portentosa



FOLIOSE
Hypogymnia physodes



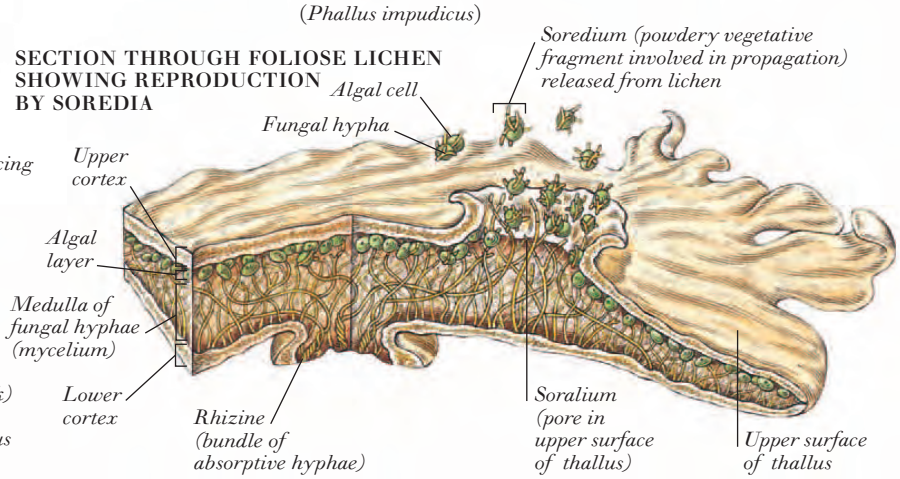
STINKHORN
(*Phallus impudicus*)

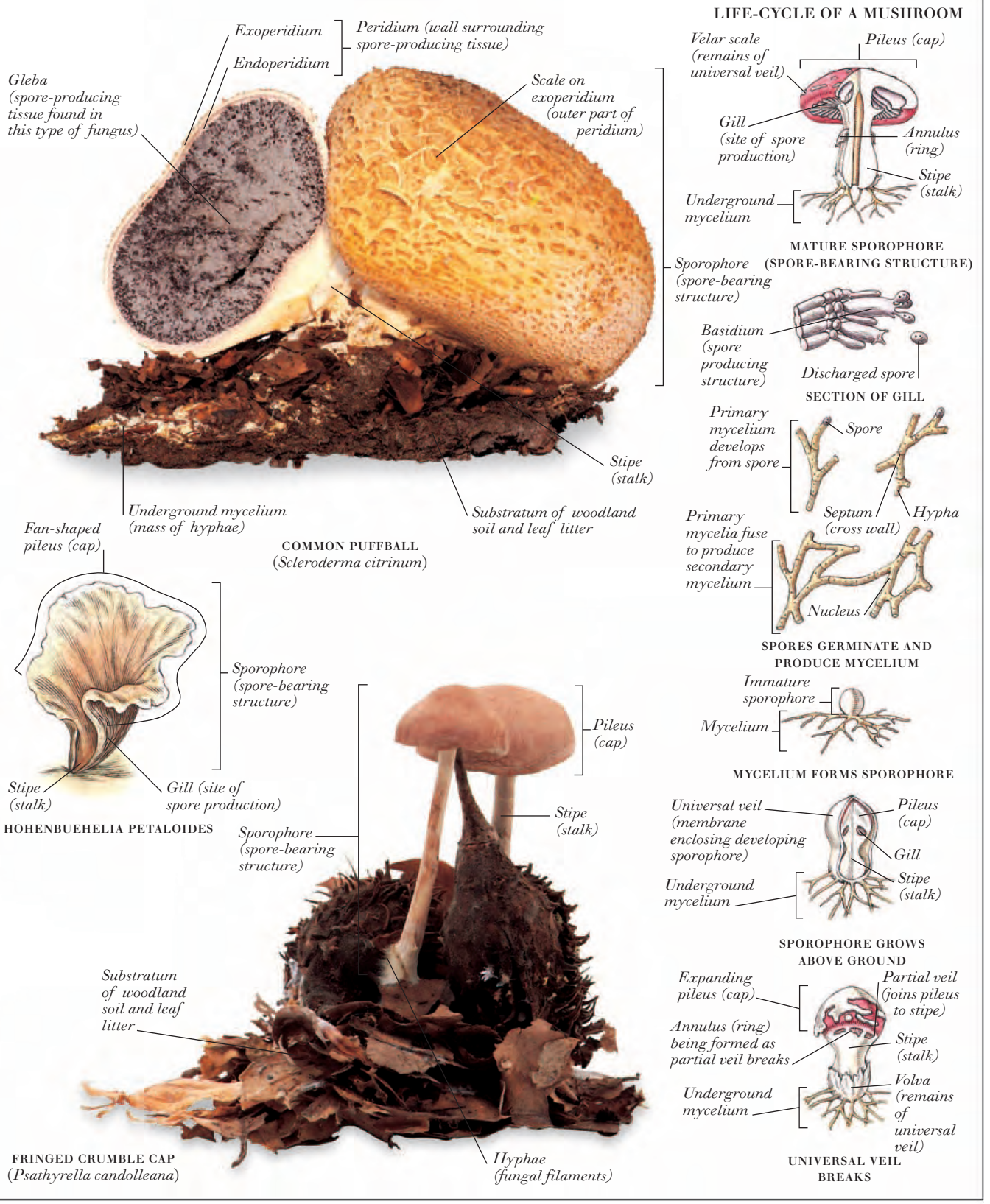


RAMARIA FORMOSA

SQUAMULOSE (SCALY) AND FRUTICOSE THALLUS
Cladonia floerkeana

SECTION THROUGH FOLIOSE LICHEN SHOWING REPRODUCTION BY SOREDIA




Exoperidium
Peridium (wall surrounding spore-producing tissue)
Endoperidium
Gleba (spore-producing tissue found in this type of fungus)
Scale on exoperidium (outer part of peridium)
Stipe (stalk)
Underground mycelium (mass of hyphae)
Substratum of woodland soil and leaf litter
COMMON PUFFBALL (Scleroderma citrinum)
Fan-shaped pileus (cap)
Sporophore (spore-bearing structure)
Stipe (stalk)
Gill (site of spore production)
HOHENBUEHELIA PETALOIDES
Pileus (cap)
Stipe (stalk)
Sporophore (spore-bearing structure)
Substratum of woodland soil and leaf litter
Hyphae (fungal filaments)
FRINGED CRUMBLE CAP (Psathyrella candolleana)
LIFE-CYCLE OF A MUSHROOM
Velar scale (remains of universal veil)
Pileus (cap)
Gill (site of spore production)
Annulus (ring)
Stipe (stalk)
Underground mycelium
MATURE SPOROPHORE (SPORE-BEARING STRUCTURE)
Sporophore (spore-bearing structure)
Basidium (spore-producing structure)
Discharged spore
SECTION OF GILL
Primary mycelium develops from spore
Spore
Septum (cross wall)
Hypha
Primary mycelia fuse to produce secondary mycelium
Nucleus
SPORES GERMINATE AND PRODUCE MYCELIUM
Immature sporophore
Mycelium
MYCELIUM FORMS SPOROPHORE
Universal veil (membrane enclosing developing sporophore)
Pileus (cap)
Gill
Stipe (stalk)
Underground mycelium
SPOROPHORE GROWS ABOVE GROUND
Expanding pileus (cap)
Partial veil (joins pileus to stipe)
Annulus (ring) being formed as partial veil breaks
Stipe (stalk)
Volva (remains of universal veil)
Underground mycelium
UNIVERSAL VEIL BREAKS

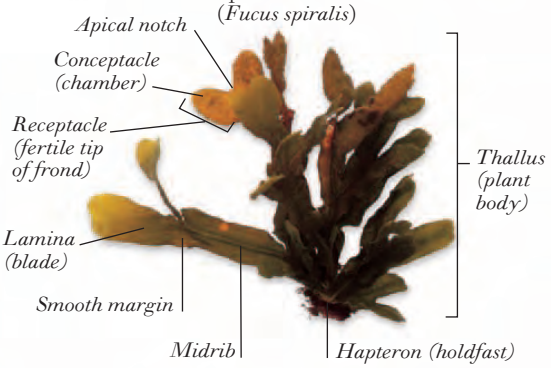
Algae and seaweeds

ALGAE ARE NOT TRUE PLANTS. They form a diverse group of plantlike organisms that belong to the kingdom Protista. Like plants, algae possess the green pigment chlorophyll and make their own food by photosynthesis (see pp. 138-139). Many algae also possess other pigments by which they can be classified; for example, the brown pigment fucoxanthin is found in the brown algae. Some of the 10 phyla of algae are exclusively unicellular (single-celled); others also contain aggregates of cells in filaments or colonies. Three phyla—the Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyta (brown algae)—contain larger, multicellular, thalloid (flat), marine organisms commonly known as seaweeds.

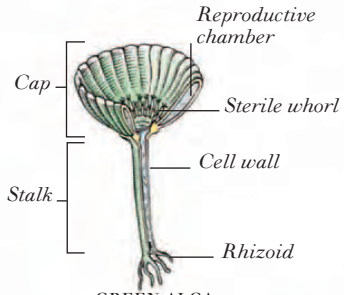
Most algae can reproduce sexually. For example, in the brown seaweed *Fucus vesiculosus*, gametes (sex cells) are produced in conceptacles (chambers) in the receptacles (fertile tips of fronds); after their release into the sea, antherozoids (male gametes) and oospheres (female gametes) fuse; the resulting zygote settles on a rock and develops into a new seaweed.

BROWN SEAWEED
Channelled wrack
(*Pelvetia canaliculata*)

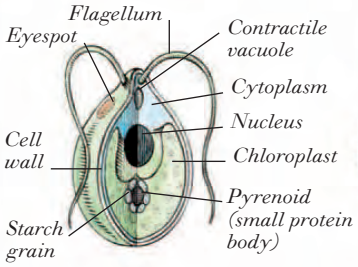
BROWN SEAWEED
Spiral wrack
(*Fucus spiralis*)



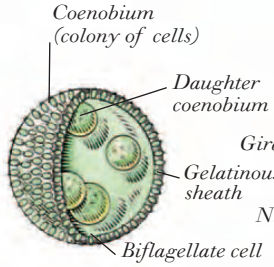
EXAMPLES OF ALGAE



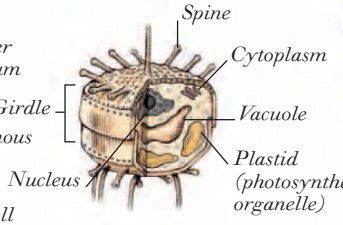
GREEN ALGA
Acetabularia sp.



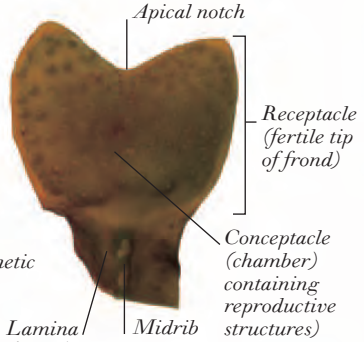
GREEN ALGA
Chlamydomonas sp.



GREEN ALGA
Volvox sp.

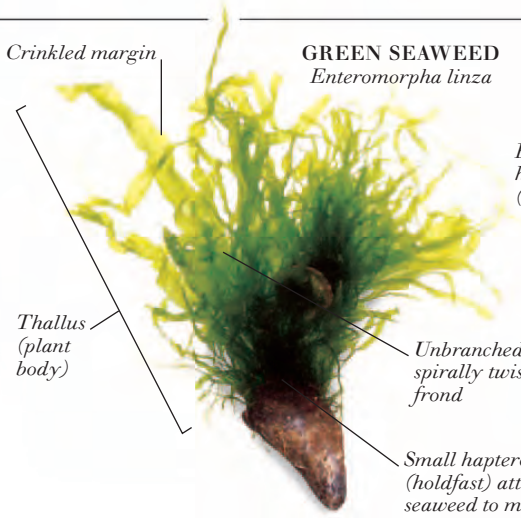


DIATOM
Thalassiosira sp.

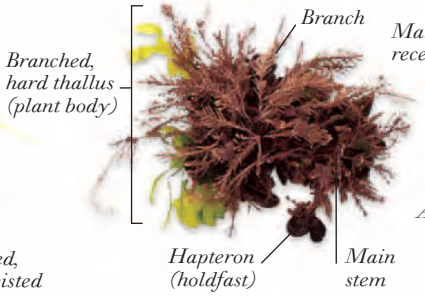


RECEPTACLE
Spiral wrack
(*Fucus spiralis*)

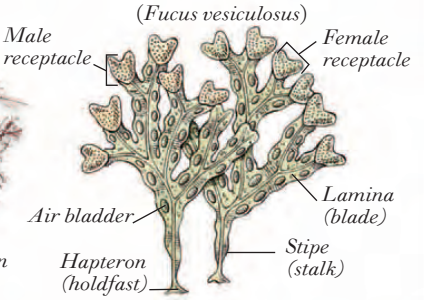
BROWN SEAWEED
Oarweed
(*Laminaria digitata*)



GREEN SEAWEED
Enteromorpha linza

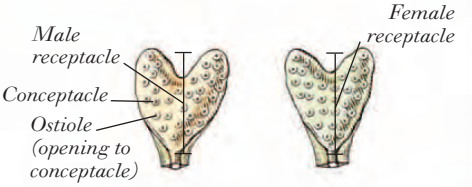


RED SEAWEED
Corallina officinalis



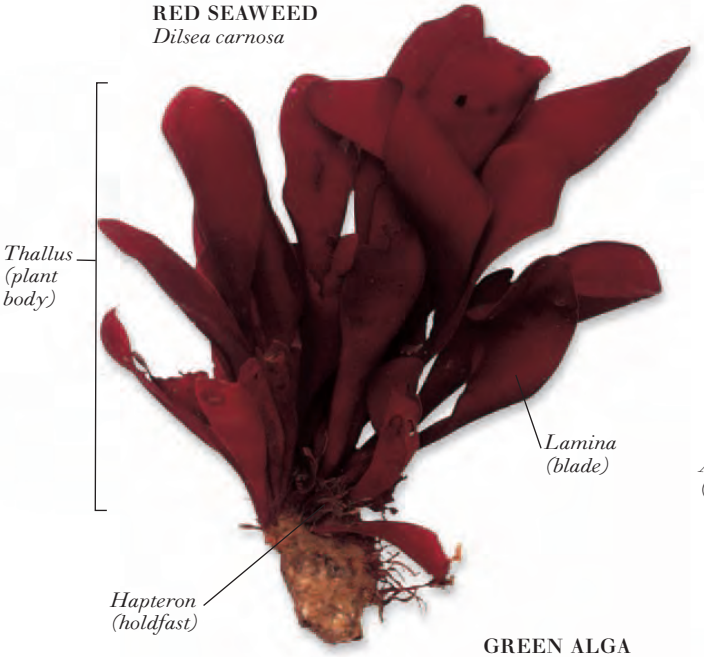
LIFE-CYCLE OF BROWN SEAWEED
Bladder wrack
(*Fucus vesiculosus*)

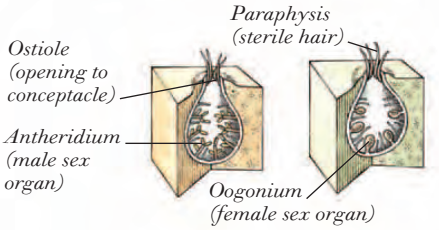
MALE AND FEMALE SEAWEEDS



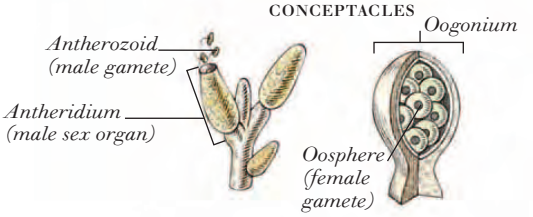
MALE AND FEMALE RECEPTACLES

RED SEAWEED
Dilsea carnosa

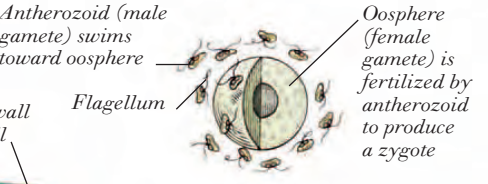




SECTIONS THROUGH MALE AND FEMALE CONCEPTACLES

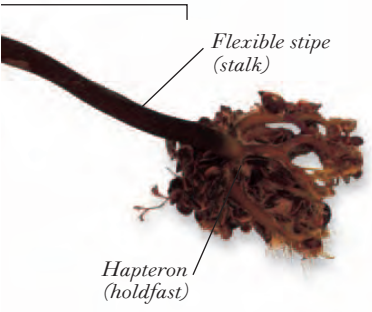


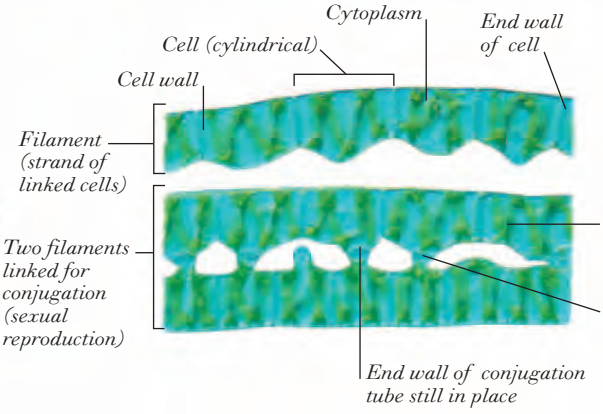
PRODUCTION OF GAMETES

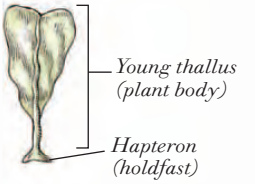


FERTILIZATION

GREEN ALGA
Spirogyra sp.







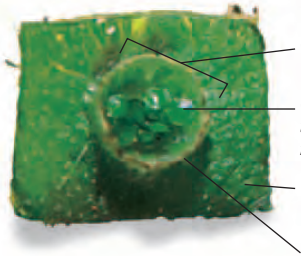
ZYGOTE DEVELOPS INTO A YOUNG SEAWEED

Liverworts and mosses

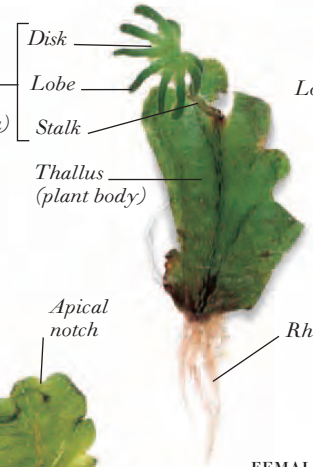
LIVERWORTS AND MOSSES ARE SMALL, LOW-GROWING PLANTS that belong to the phylum Bryophyta. Bryophytes do not have true stems, leaves, or roots (they are anchored to the ground by rhizoids), nor do they have the vascular tissues (xylem and phloem) that transport water and nutrients in higher plants. With no outer, waterproof cuticle, bryophytes are susceptible to drying out, and most grow in moist habitats. The bryophyte life-cycle has two stages. In stage one, the green plant (gametophyte) produces male and female gametes (sex cells), which fuse to form a zygote. In stage two, the zygote develops into a sporophyte that remains attached to the gametophyte. The sporophyte produces spores, which are released and germinate into new green plants. Liverworts (class Hepaticae) grow horizontally and may be thalloid (flat and ribbonlike) or "leafy." Mosses (class Musci) typically have an upright "stem" with spirally arranged "leaves."

A LEAFY LIVERWORT
Scapania undulata

A THALLOID LIVERWORT
Marchantia polymorpha

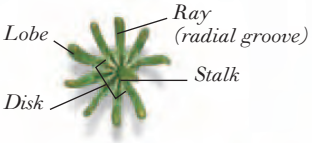


DETAIL OF GEMMA CUP

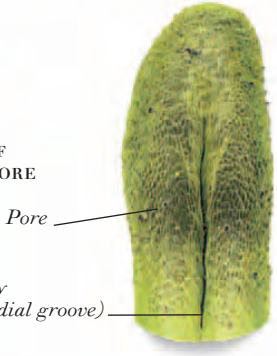


FEMALE GAMETOPHYTE

SIDE VIEW OF ARCHEGONIOPHORE

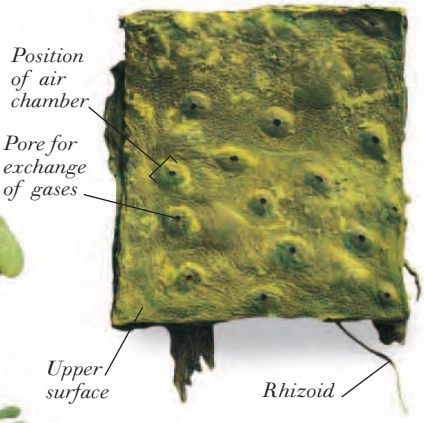


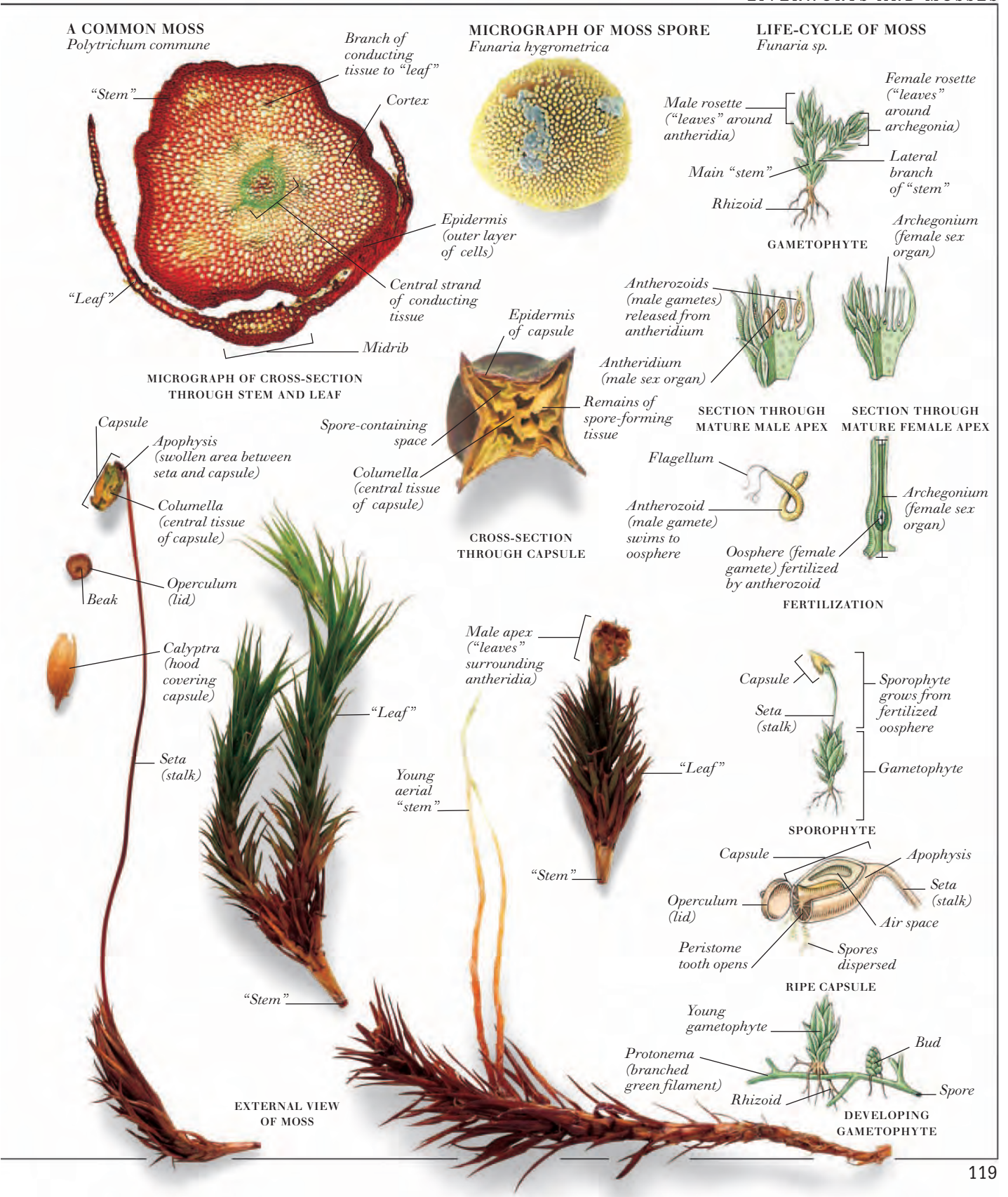
ARCHEGONIOPHORE FROM BELOW



MICROGRAPH OF LOBE

MICROGRAPH OF THALLUS
Conocephalum conicum




A COMMON MOSS
Polytrichum commune
Branch of conducting tissue to "leaf"
"Stem"
Cortex
Epidermis (outer layer of cells)
"Leaf"
Central strand of conducting tissue
Midrib
MICROGRAPH OF CROSS-SECTION THROUGH STEM AND LEAF
MICROGRAPH OF MOSS SPORE
Funaria hygrometrica
LIFE-CYCLE OF MOSS
Funaria sp.
Male rosette ("leaves" around antheridia)
Female rosette ("leaves" around archegonia)
Lateral branch of "stem"
Main "stem"
Rhizoid
GAMETOPHYTE
Archegonium (female sex organ)
Antherozoids (male gametes) released from antheridium
Antheridium (male sex organ)
SECTION THROUGH MATURE MALE APEX
SECTION THROUGH MATURE FEMALE APEX
Epidermis of capsule
Remains of spore-forming tissue
Spore-containing space
Columella (central tissue of capsule)
CROSS-SECTION THROUGH CAPSULE
Flagellum
Antherozoid (male gamete) swims to oosphere
Archegonium (female sex organ)
Oosphere (female gamete) fertilized by antherozoid
FERTILIZATION
Capsule
Apophysis (swollen area between seta and capsule)
Columella (central tissue of capsule)
Beak
Operculum (lid)
Calyptra (hood covering capsule)
Seta (stalk)
"Leaf"
"Stem"
EXTERNAL VIEW OF MOSS
Male apex ("leaves" surrounding antheridia)
"Leaf"
Young aerial "stem"
"Stem"
Capsule
Seta (stalk)
Sporophyte grows from fertilized oosphere
Gametophyte
SPOROPHYTE
Capsule
Apophysis
Seta (stalk)
Operculum (lid)
Air space
Peristome tooth opens
Spores dispersed
RIPE CAPSULE
Young gametophyte
Bud
Protonema (branched green filament)
Rhizoid
Spore
DEVELOPING GAMETOPHYTE

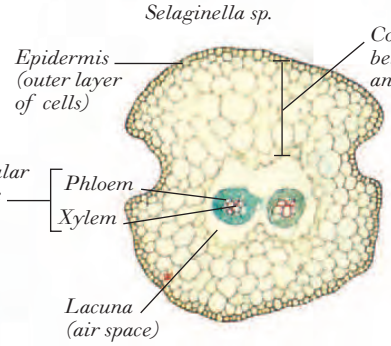
Horsetails, clubmosses, and ferns

FROND
Male fern
(*Dryopteris filix-mas*)

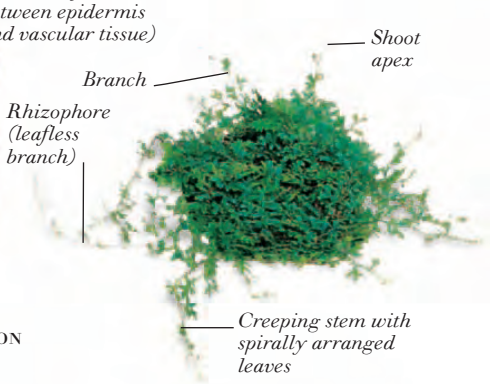
HORSETAILS, CLUBMOSSES, AND FERNS are primitive land plants, which, like higher plants, have stems, roots, and leaves, and vascular systems that transport water, minerals, and food. However, unlike higher plants, they do not produce seeds when reproducing. Their life-cycles involve two stages. In stage one, the sporophyte (green plant) produces spores in sporangia. In stage two, the spores germinate, developing into small, short-lived gametophyte plants that produce male and female gametes (sex cells); the gametes fuse to form a zygote from which a new sporophyte plant develops. Horsetails (phylum Sphenophyta) have erect, green stems with branches arranged in whorls; some stems are fertile and have a single spore-producing strobilus (group of sporangia) at the tip. Clubmosses (phylum Lycopodophyta) typically have small leaves arranged spirally around the stem, with spore-producing strobili at the tip of some stems. Ferns (phylum Filicinophyta) typically have large, pinnate fronds (leaves); sporangia, grouped together in sori, develop on the underside of fertile fronds.

CLUBMOSS
Lycopodium sp.

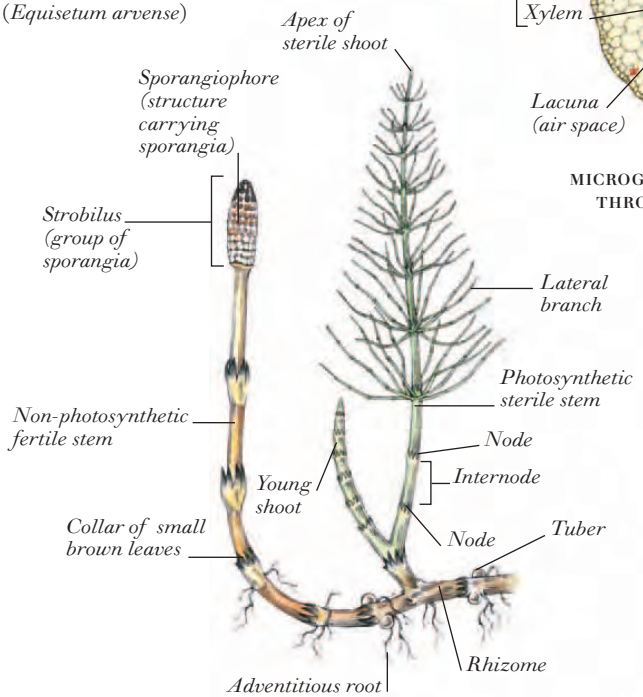
CLUBMOSS
Selaginella sp.

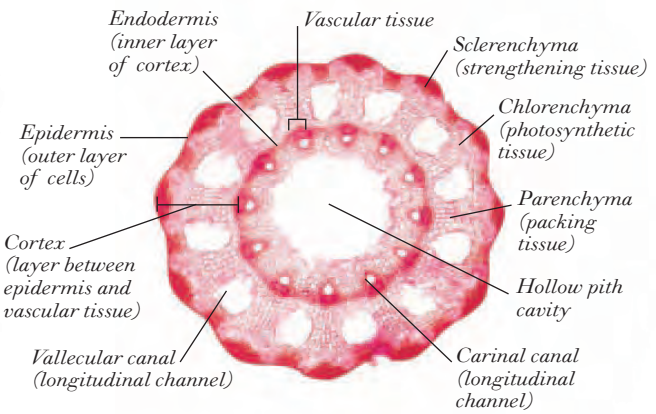


MICROGRAPH OF CROSS-SECTION THROUGH CLUBMOSS STEM



HORSETAIL
Common horsetail
(*Equisetum arvense*)

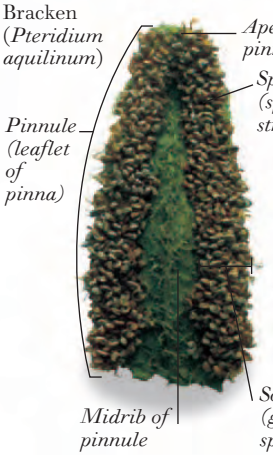




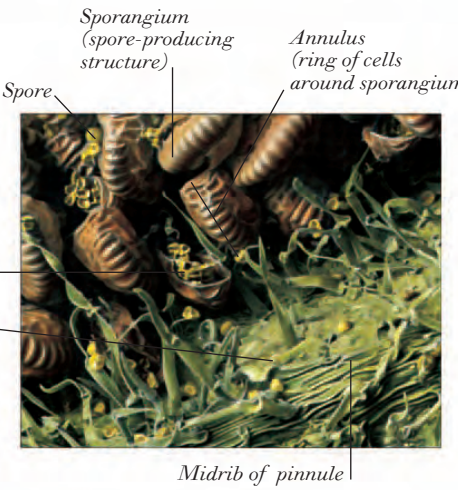
MICROGRAPH OF CROSS-SECTION THROUGH HORSETAIL STEM

SPORE PRODUCTION IN FERN

Bracken (*Pteridium aquilinum*)

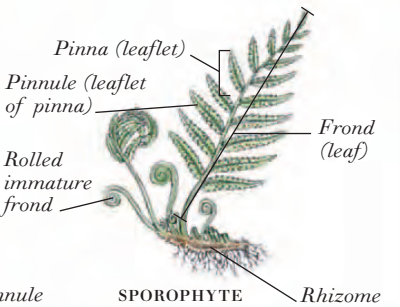


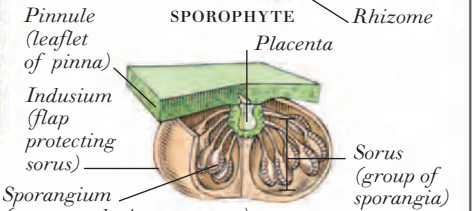
MICROGRAPH OF LOWER SURFACE OF FERTILE PINNULE



MICROGRAPH OF SPORANGIA ON LOWER SURFACE OF FERTILE PINNULE

LIFE-CYCLE OF FERN

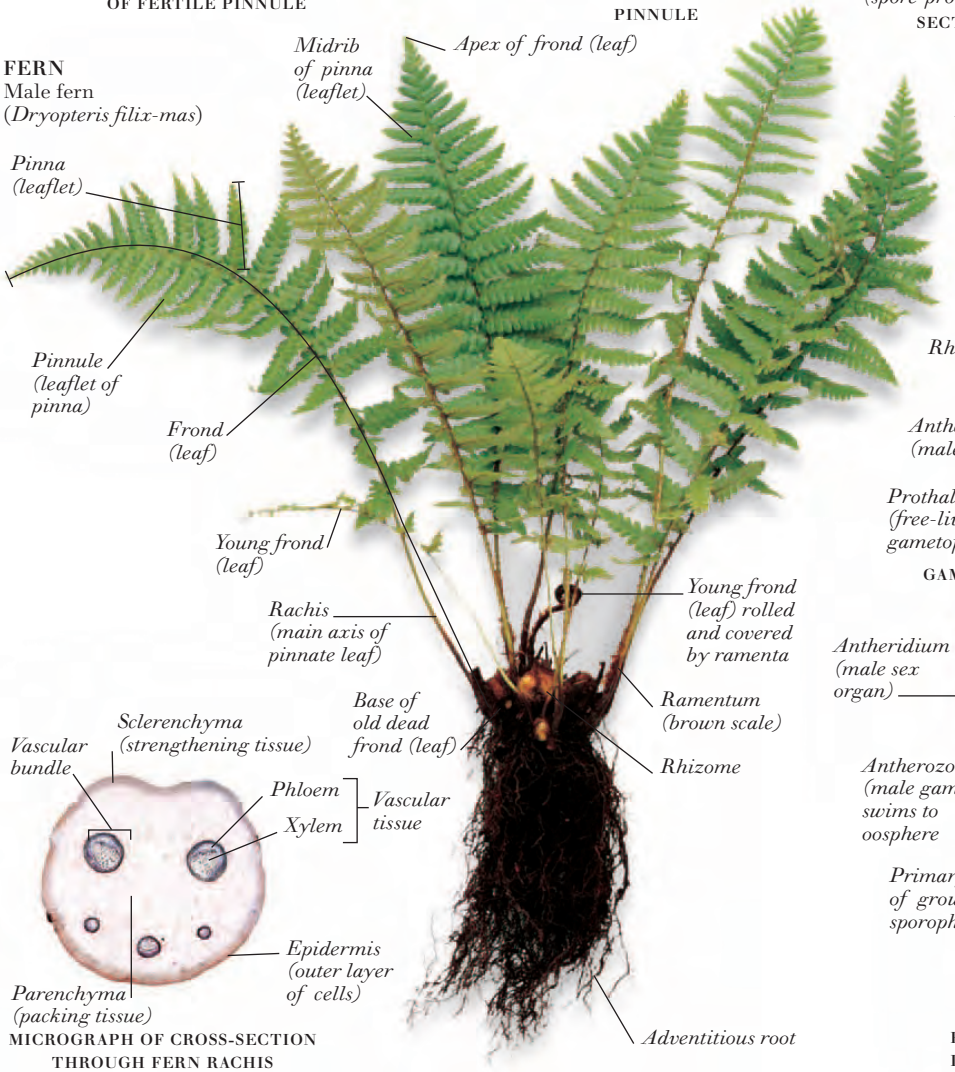




SECTION THROUGH MATURE PINNULE

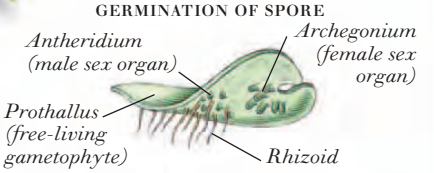
FERN

Male fern (*Dryopteris filix-mas*)



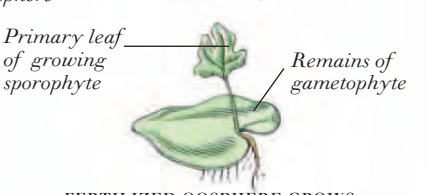
RELEASE OF SPORES FROM SPORANGIUM

GERMINATION OF SPORE



GAMETOPHYTE PRODUCES GAMETES

FERTILIZATION

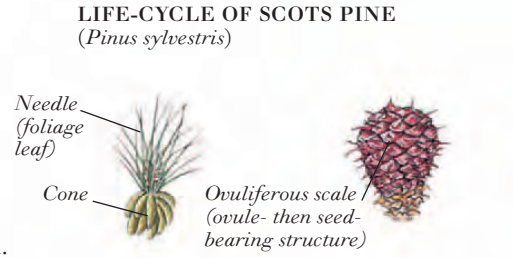


FERTILIZED OOSPHERE GROWS INTO NEW SPOROPHYTE PLANT

MICROGRAPH OF CROSS-SECTION THROUGH FERN RACHIS

Gymnosperms 1

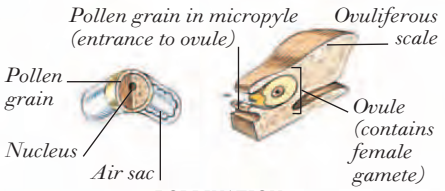
THE GYMNOSPERMS ARE FOUR RELATED PHYLA of seed-producing plants; their seeds, however, lack the protective, outer covering that surrounds the seeds of flowering plants. Typically, gymnosperms are woody, perennial shrubs or trees, with stems, leaves, and roots, and a well-developed vascular (transportat) system. The reproductive structures in most gymnosperms are cones: male cones produce microspores in which male gametes (sex cells) develop; female cones produce megaspores in which female gametes develop. Microspores are blown by the wind to female cones, male and female gametes fuse during fertilization, and a seed develops. The four gymnosperm phyla are the conifers (phylum Coniferophyta), mostly tall trees; cycads (phylum Cycadophyta), small palmlike trees; the ginkgo or maidenhair tree (phylum Ginkgophyta), a tall tree with bilobed leaves; and gnetophytes (phylum Gnetophyta), a diverse group of plants, mainly shrubs, but also including the horizontally growing welwitschia.



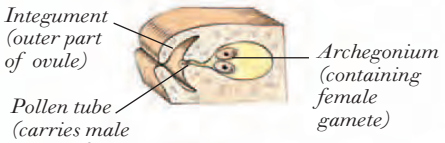
LIFE-CYCLE OF SCOTS PINE
(*Pinus sylvestris*)

MALE CONES

YOUNG FEMALE CONE

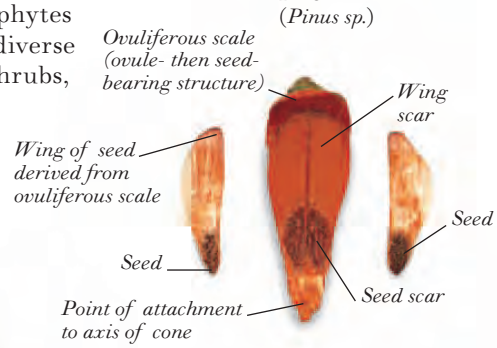


POLLINATION

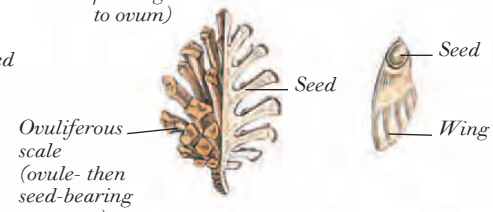


FERTILIZATION

SCALE AND SEEDS
Pine
(*Pinus sp.*)

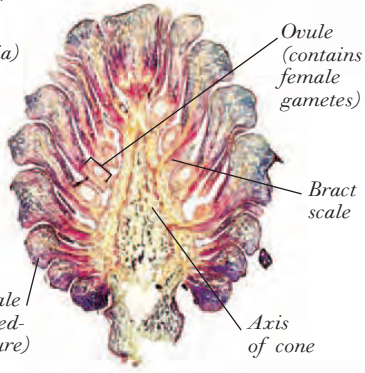


OVULIFEROUS SCALE FROM THIRD-YEAR FEMALE CONE

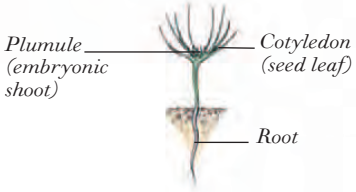


MATURE FEMALE CONE AND WINGED SEED

MICROGRAPH OF LONGITUDINAL SECTION THROUGH YOUNG MALE CONE



MICROGRAPH OF LONGITUDINAL SECTION THROUGH SECOND-YEAR FEMALE CONE

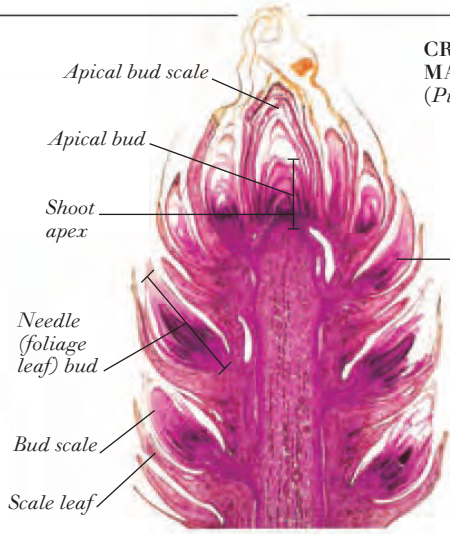


GERMINATION OF PINE SEEDLING

WELWITSCHIA
(*Welwitschia mirabilis*)

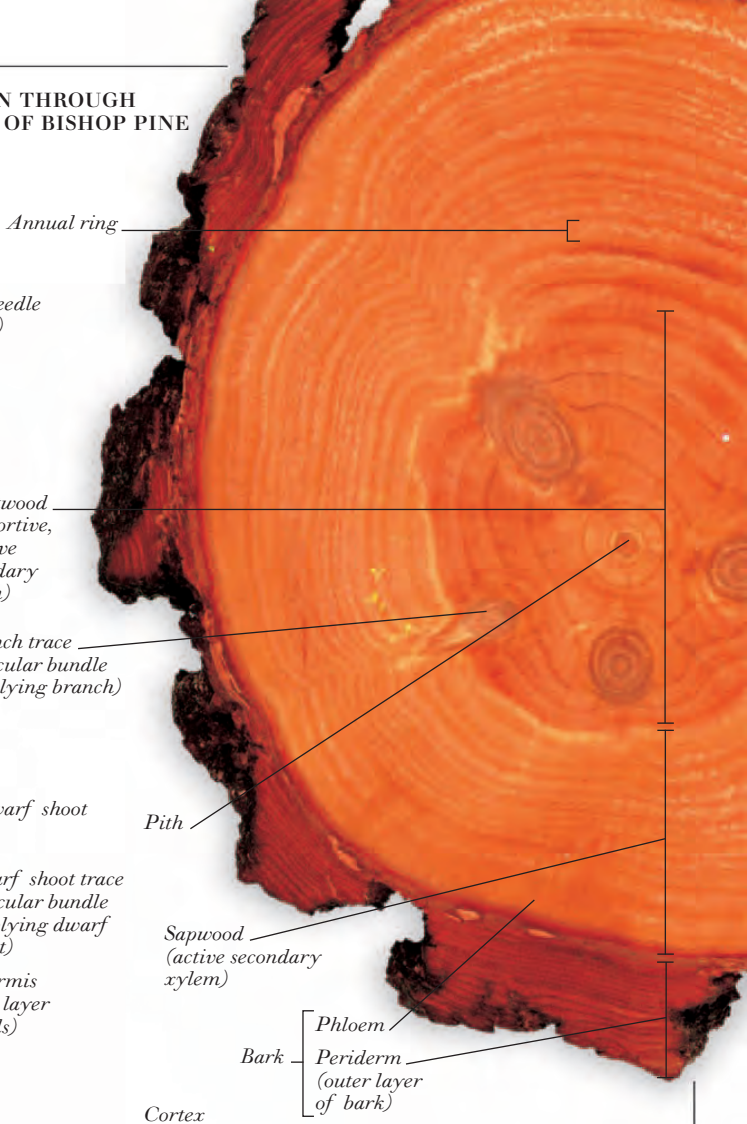
SMOOTH CYPRESS
(Cupressus glabra)
Immature female cone
Ovuliferous scale (ovule- then seed-bearing structure)
Scalelike leaf
Mature female cone
Immature male cone
Stem
Ovuliferous scale
Ovule (contains female gamete)
CROSS-SECTION THROUGH IMMATURE CONE
Seed
Ovuliferous scale (ovule- then seed-bearing structure)
CROSS-SECTION THROUGH MATURE CONE
Woody scale
Opening between woody scales through which seeds are released
DISCARDED CONE
YEW
(Taxus baccata)
Single ovule (contains female gamete)
Scale
Female "cone"
Scale
Developing seed
Scale
FEMALE "CONES" AT VARIOUS STAGES OF DEVELOPMENT
Seed
Aril (fleshy outgrowth from seed)
Stem
Needle (foliage leaf)
CYCAD
Sago palm
(Cycas revoluta)
Pinna (leaflet)
Pinnate leaf
Scale leaf
Old leaf base
Stem covered by scale leaves
MAIDENHAIR TREE
(Ginkgo biloba)
Girdle scar
Stem
Petiole (leaf stalk)
Bilobed leaf
Continuously growing leaf
Site of cone growth
Adaxial (upper) surface of leaf
Frayed end of leaf
Abaxial (lower) surface of leaf
Immature cone
Stalk scar
Woody stem

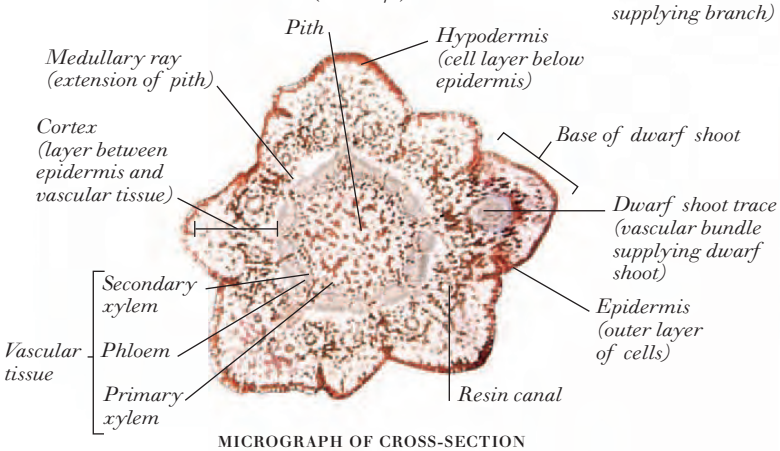
Gymnosperms 2



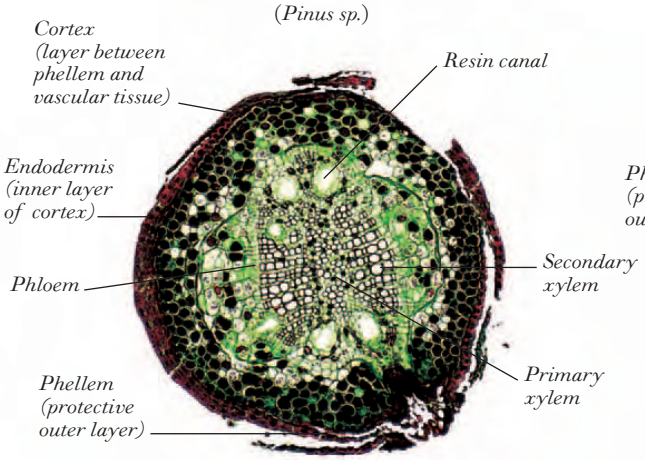
MICROGRAPH OF LONGITUDINAL SECTION THROUGH SHOOT APEX OF PINE (*Pinus sp.*)

CROSS-SECTION THROUGH MATURE STEM OF BISHOP PINE (*Pinus muricata*)

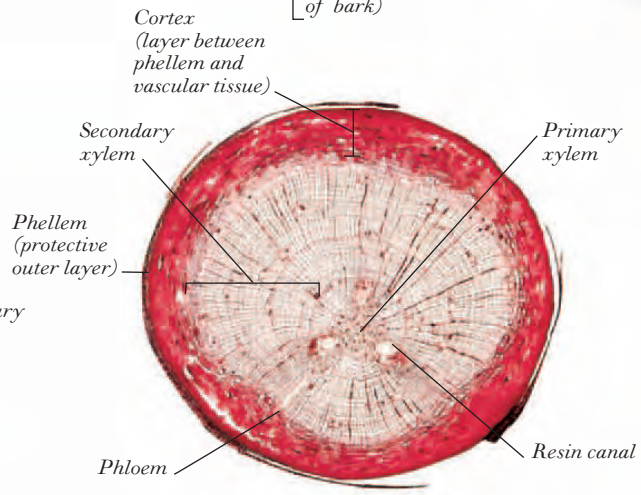




MICROGRAPH OF CROSS-SECTION THROUGH YOUNG STEM OF PINE (*Pinus sp.*)



MICROGRAPH OF CROSS-SECTION THROUGH YOUNG ROOT OF PINE (*Pinus sp.*)



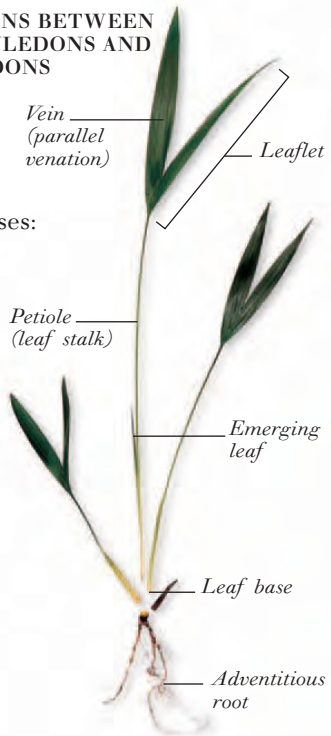
MICROGRAPH OF CROSS-SECTION THROUGH MATURE ROOT OF PINE (*Pinus sp.*)

Monocotyledons and dicotyledons

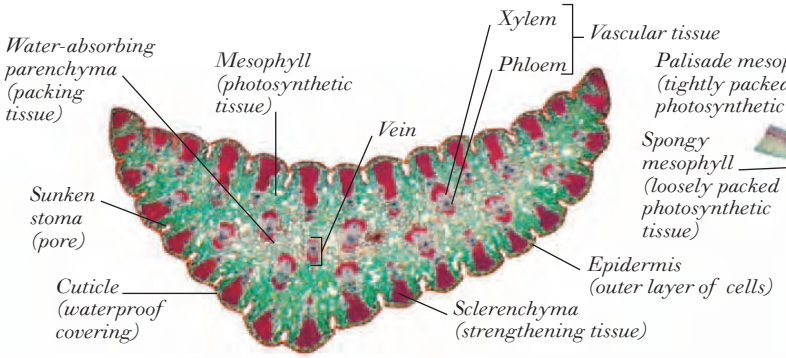
FLOWERING PLANTS (PHYLUM ANGIOSPERMOPHYTA) are divided into two classes: monocotyledons (class Monocotyledoneae) and dicotyledons (class Dicotyledoneae). Typically, monocotyledons have seeds with one cotyledon (seed leaf); their foliage leaves are narrow with parallel veins; the flower components occur in multiples of three; sepals and petals are indistinguishable and are known as tepals; vascular (transport) tissues are scattered in random bundles throughout the stem; and, since they lack stem cambium (actively dividing cells that produce wood), most monocotyledons are herbaceous (see pp. 128-129). Dicotyledons have seeds with two cotyledons; leaves are broad with a central midrib and branched veins; flower parts occur in multiples of four or five; sepals are generally small and green; petals are large and colorful; vascular bundles are arranged in a ring around the edge of the stem; and, because many dicotyledons possess wood-producing stem cambium, there are woody forms (see pp. 130-131) as well as herbaceous ones.

CROSS-SECTION THROUGH MONOCOTYLEDONOUS LEAF BASES

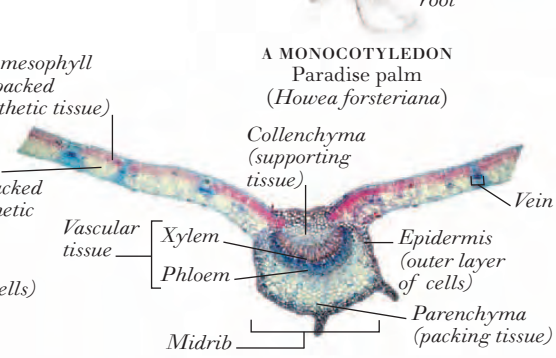
COMPARISONS BETWEEN MONOCOTYLEDONS AND DICOTYLEDONS



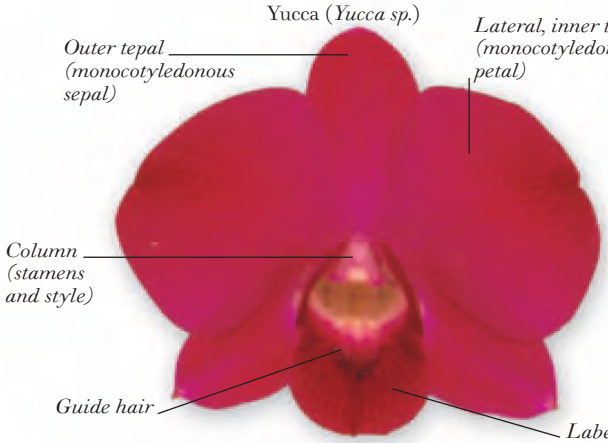
A MONOCOTYLEDON
Paradise palm
(*Howea forsteriana*)



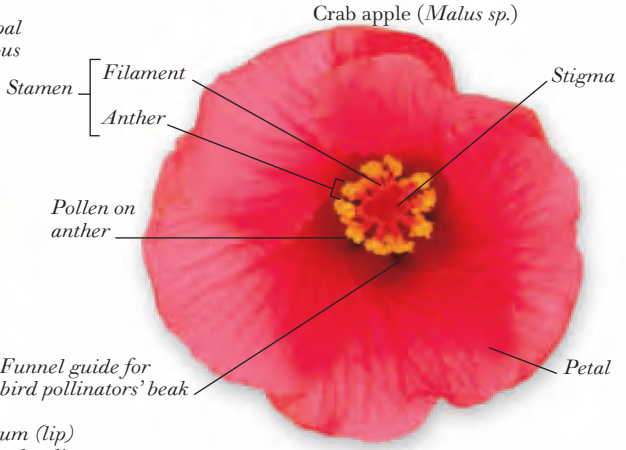
MICROGRAPH OF CROSS-SECTION THROUGH A MONOCOTYLEDONOUS LEAF
Yucca (*Yucca sp.*)



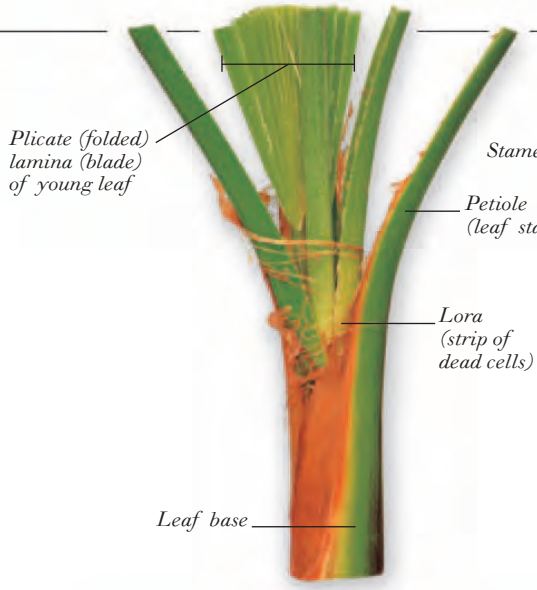
MICROGRAPH OF CROSS-SECTION THROUGH A DICOTYLEDONOUS LEAF
Crab apple (*Malus sp.*)



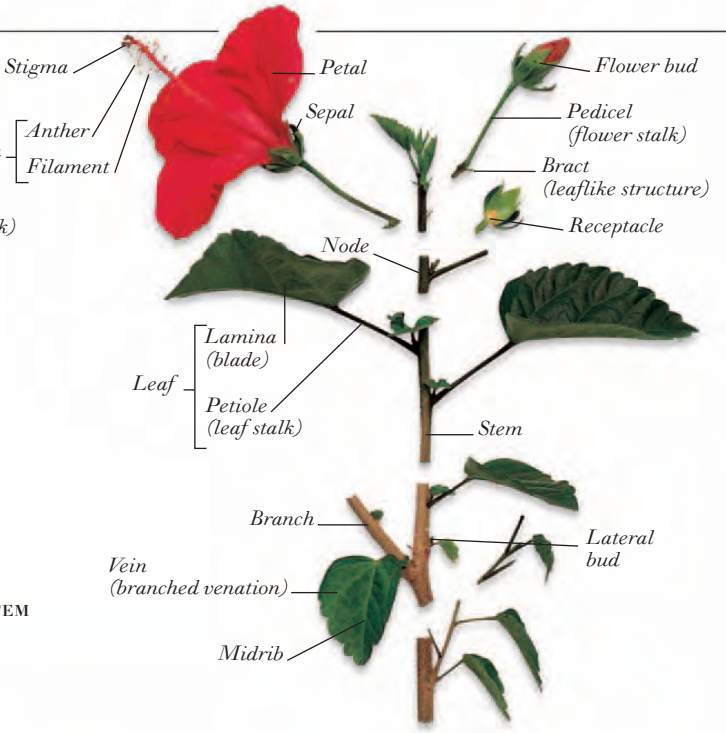
A MONOCOTYLEDONOUS FLOWER
Orchid
(*Phalaenopsis sp.*)

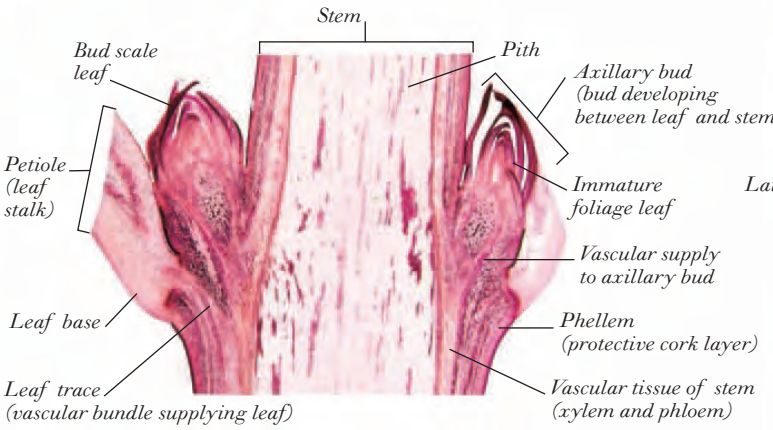


A DICOTYLEDONOUS FLOWER
Hibiscus
(*Hibiscus rosa-sinensis*)

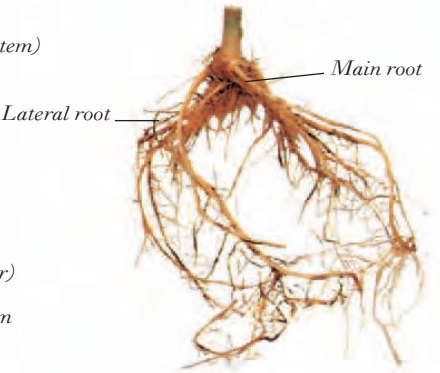


MONOCOTYLEDONOUS LEAF BASES FORMING STEM
Chusan palm
(*Trachycarpus fortunei*)

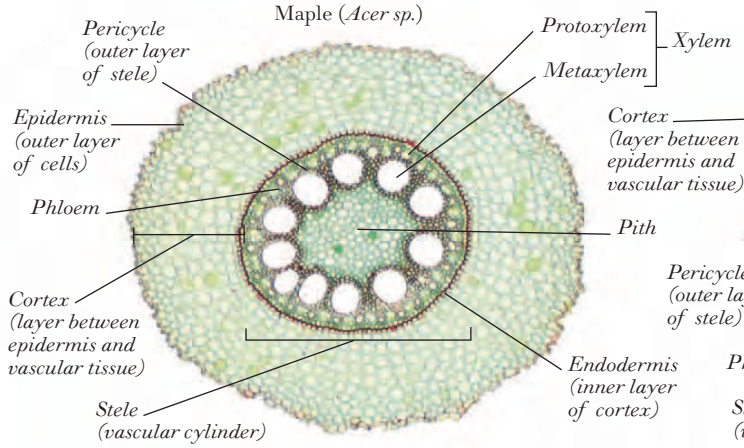




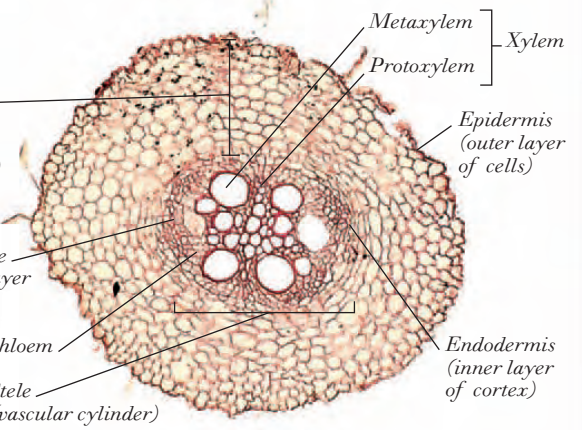
MICROGRAPH OF LONGITUDINAL SECTION THROUGH A WOODY DICOTYLEDONOUS STEM
Maple (*Acer sp.*)



A DICOTYLEDON
Hibiscus (*Hibiscus rosa-sinensis*)



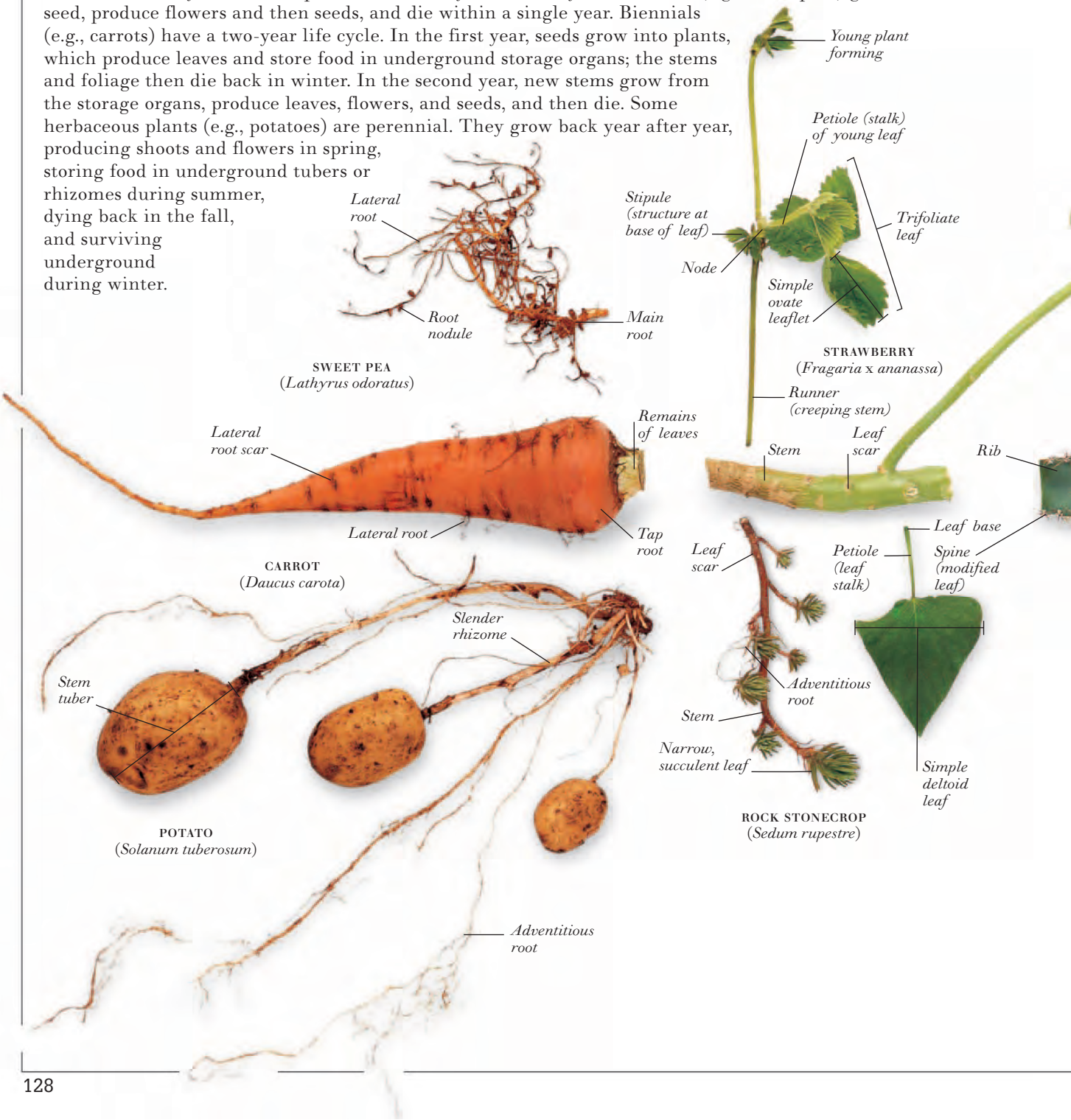
MICROGRAPH OF CROSS-SECTION THROUGH A MONOCOTYLEDONOUS ROOT
Corn (*Zea mays*)



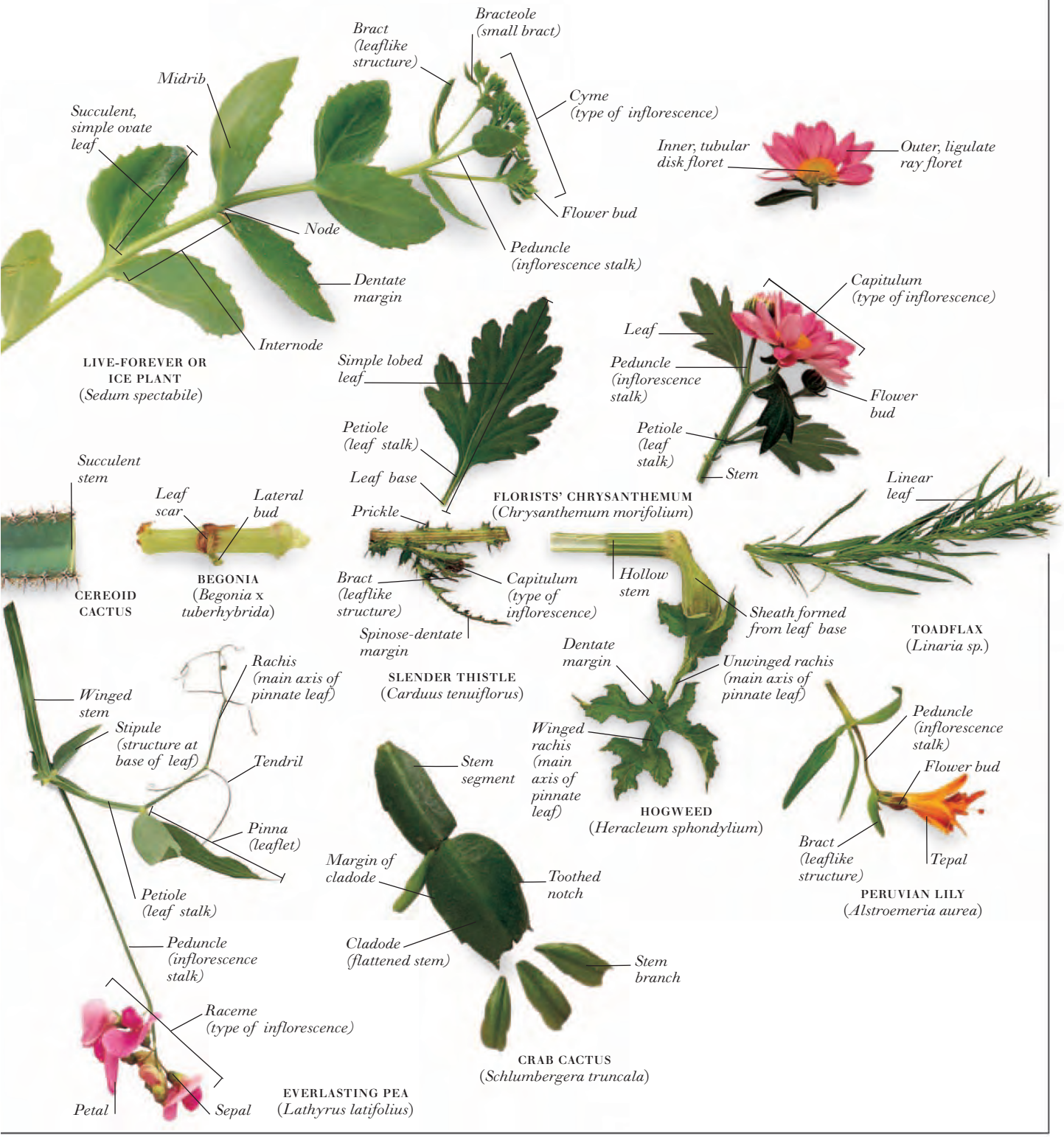
MICROGRAPH OF CROSS-SECTION THROUGH A DICOTYLEDONOUS ROOT
Buttercup (*Ranunculus sp.*)

Herbaceous flowering plants

HERBACEOUS FLOWERING PLANTS TYPICALLY HAVE GREEN, NON-WOODY STEMS, and tend to be relatively short-lived. Many herbaceous plants live for only one or two years. Annuals (e.g., sweet peas) grow from seed, produce flowers and then seeds, and die within a single year. Biennials (e.g., carrots) have a two-year life cycle. In the first year, seeds grow into plants, which produce leaves and store food in underground storage organs; the stems and foliage then die back in winter. In the second year, new stems grow from the storage organs, produce leaves, flowers, and seeds, and then die. Some herbaceous plants (e.g., potatoes) are perennial. They grow back year after year, producing shoots and flowers in spring, storing food in underground tubers or rhizomes during summer, dying back in the fall, and surviving underground during winter.



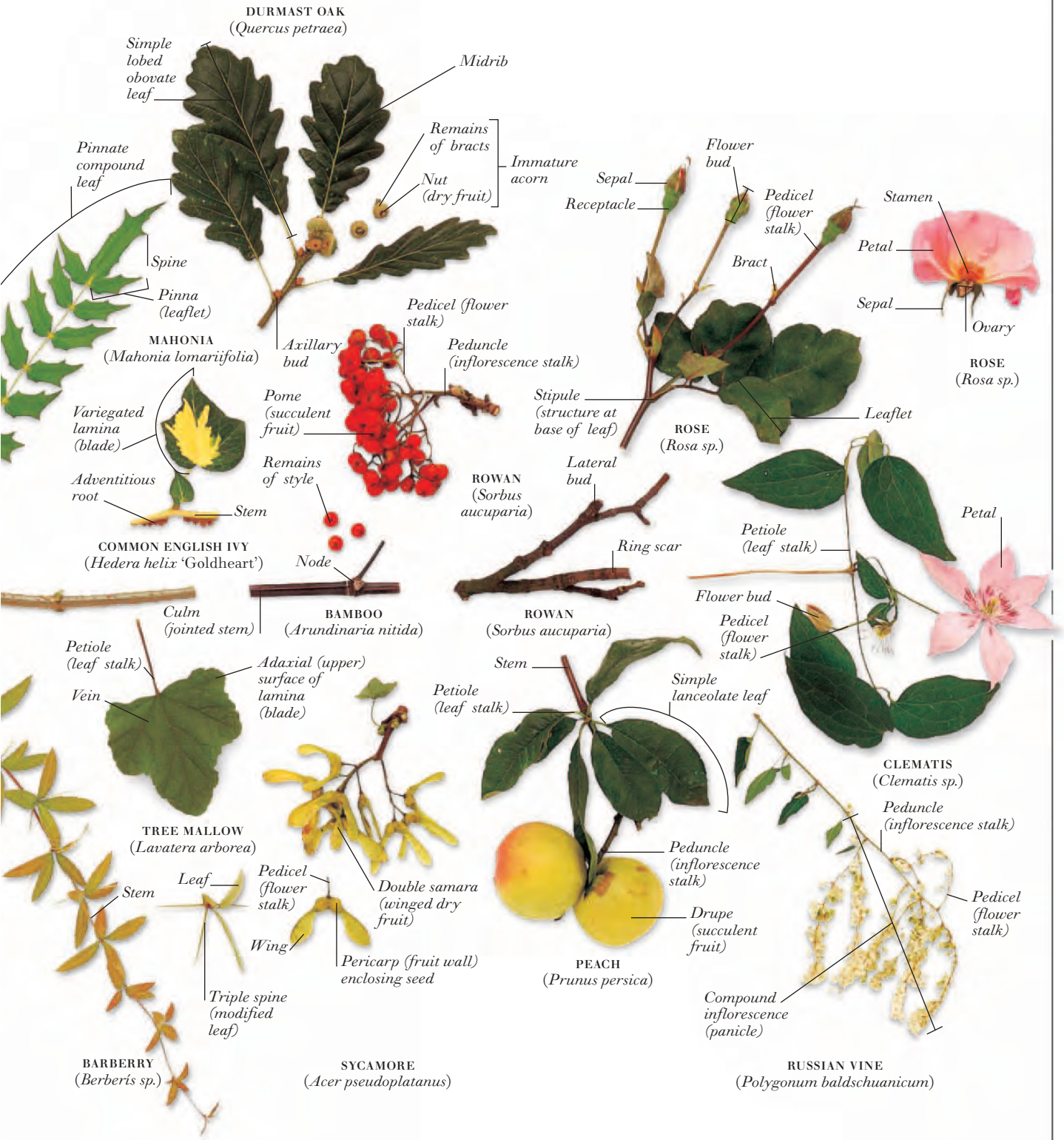
PARTS OF HERBACEOUS FLOWERING PLANTS



Woody flowering plants

WOODY FLOWERING PLANTS ARE PERENNIAL, that is, they continue to grow and reproduce for many years. They have one or more permanent stems above ground, and numerous smaller branches. The stems and branches have a strong woody core that supports the plant and contains vascular tissue for transporting water and nutrients. Outside the woody core is a layer of tough, protective bark, which has lenticels (tiny pores) in it to enable gases to pass through. Woody flowering plants may be shrubs, which have several stems arising from the soil; bushes, which are shrubs with dense branching and foliage; or trees, which typically have a single upright stem (the trunk) that bears branches. Deciduous woody plants (e.g., roses) shed all their leaves once a year and remain leafless during winter. Evergreen woody plants (e.g., ivy) shed their leaves gradually, so retaining full leaf cover throughout the year.

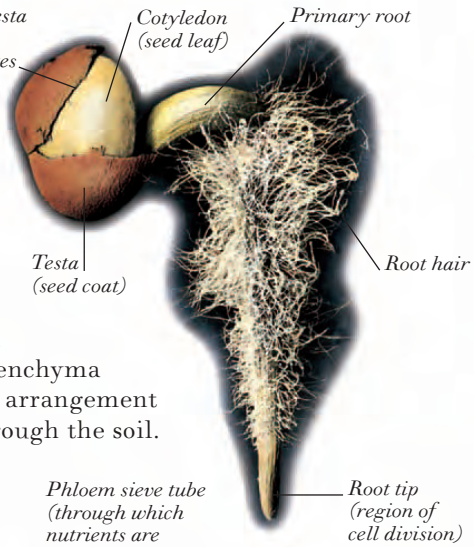
PARTS OF WOODY FLOWERING PLANTS



Roots

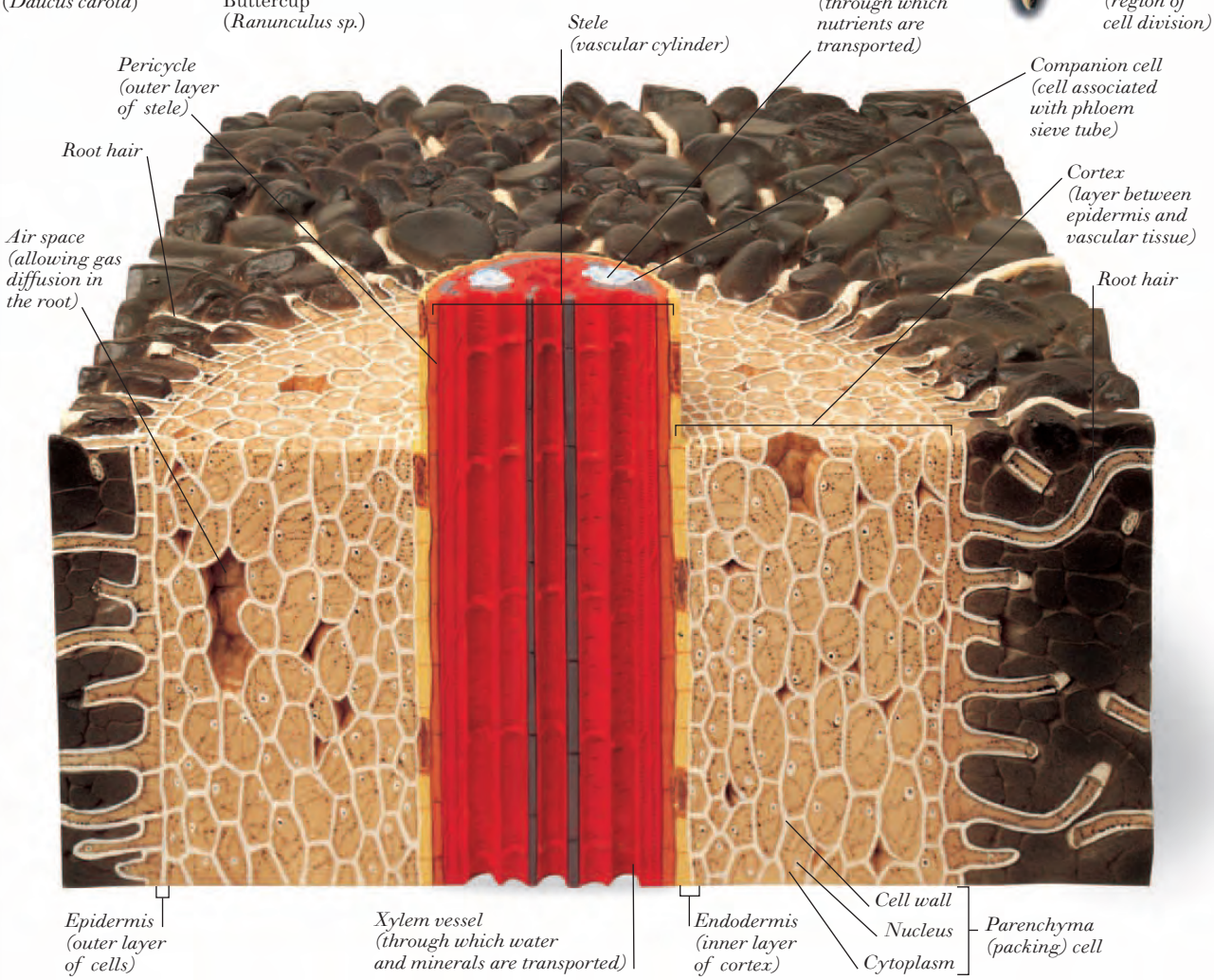
ROOTS ARE THE UNDERGROUND PARTS OF PLANTS. They have three main functions. First, they anchor the plant in the soil. Second, they absorb water and minerals from the spaces between soil particles; the roots' absorptive properties are increased by root hairs, which grow behind the root tip, allowing maximum uptake of vital substances. Third, the root is part of the plant's transport system: xylem carries water and minerals from the roots to the stem and leaves, and phloem carries nutrients from the leaves to all parts of the root system. In addition, some roots (e.g., carrots) are food stores. Roots have an outer epidermis covering a cortex of parenchyma (packing tissue), and a central cylinder of vascular tissue. This arrangement helps the roots resist the forces of compression as they grow through the soil.

MICROGRAPH OF PRIMARY ROOT DEVELOPMENT
Cabbage (*Brassica sp.*)

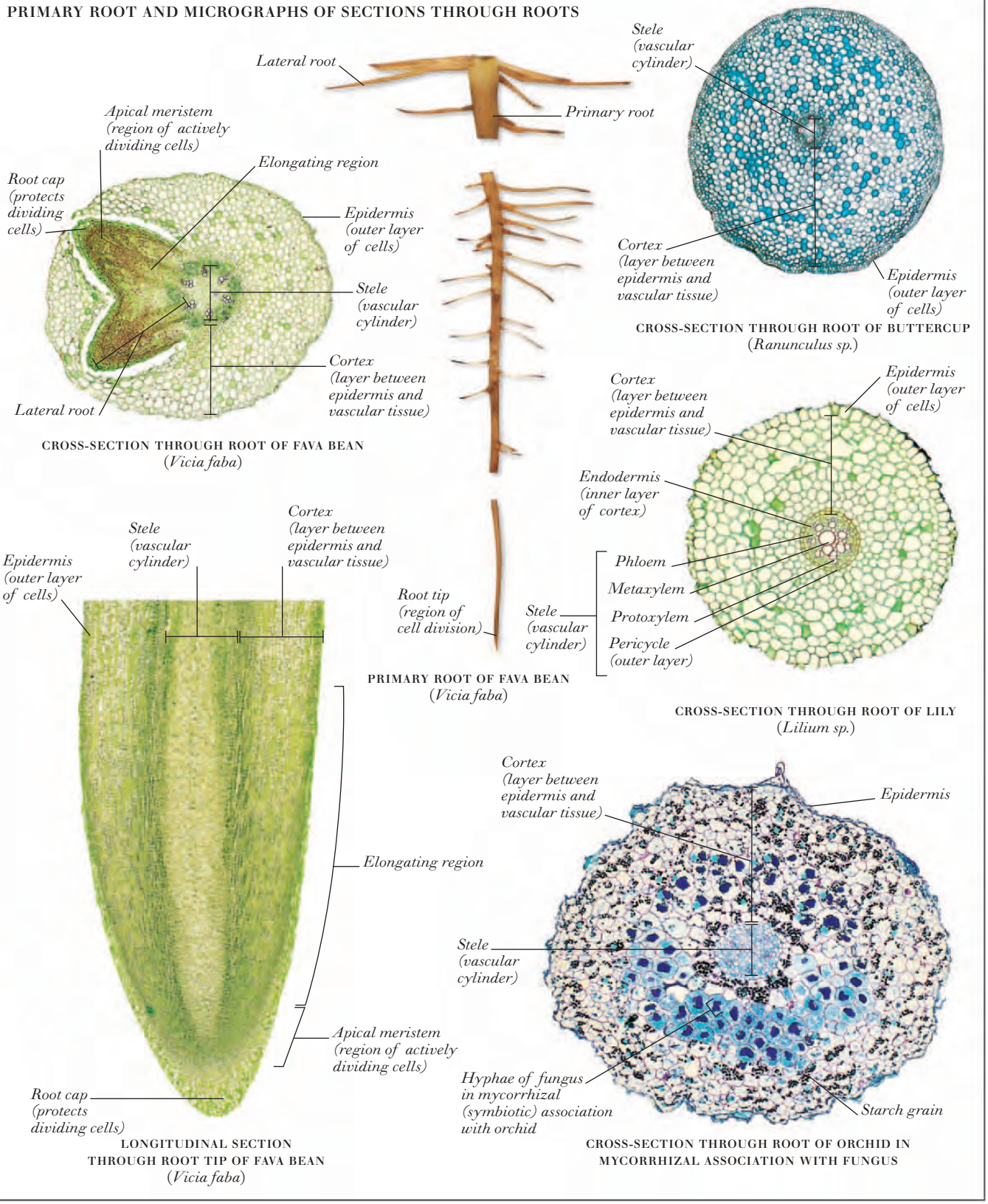


CARROT
(*Daucus carota*)

FEATURES OF A TYPICAL ROOT
Buttercup
(*Ranunculus sp.*)



PRIMARY ROOT AND MICROGRAPHS OF SECTIONS THROUGH ROOTS



CROSS-SECTION THROUGH ROOT OF FAVA BEAN
(*Vicia faba*)

PRIMARY ROOT OF FAVA BEAN
(*Vicia faba*)

CROSS-SECTION THROUGH ROOT OF BUTTERCUP
(*Ranunculus sp.*)

CROSS-SECTION THROUGH ROOT OF LILY
(*Lilium sp.*)

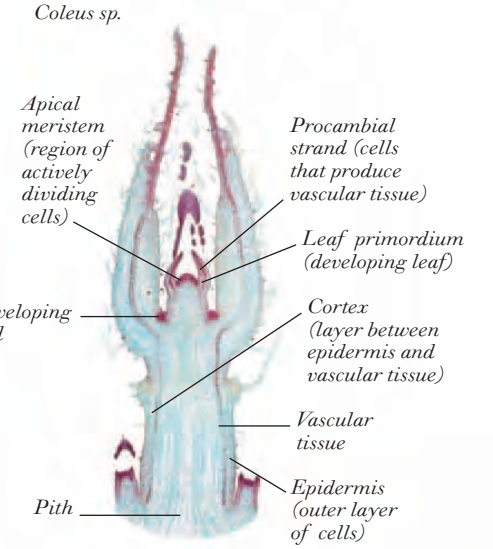
LONGITUDINAL SECTION
THROUGH ROOT TIP OF FAVA BEAN
(*Vicia faba*)

CROSS-SECTION THROUGH ROOT OF ORCHID IN
MYCORRHIZAL ASSOCIATION WITH FUNGUS

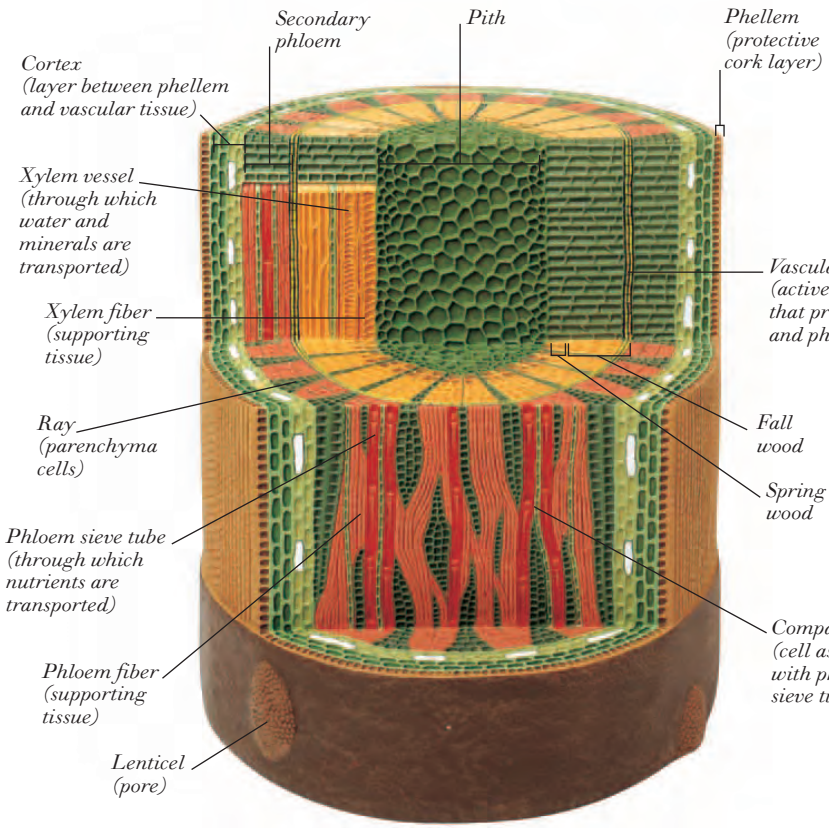
Stems

THE STEM IS THE MAIN SUPPORTIVE PART OF A PLANT that grows above ground. Stems bear leaves (organs of photosynthesis), which grow at nodes; buds (shoots covered by protective scales), which grow at the stem tip (apical or terminal buds) and in the angle between a leaf and the stem (axillary or lateral buds); and flowers (reproductive structures). The stem forms part of the plant's transport system: xylem tissue in the stem transports water and minerals from the roots to the aerial parts of the plant, and phloem tissue transports nutrients manufactured in the leaves to other parts of the plant. Stem tissues are also used for storing water and food. Herbaceous (non-woody) stems have an outer protective epidermis covering a cortex that consists mainly of parenchyma (packing tissue) but also has some collenchyma (supporting tissue). The vascular tissue of such stems is arranged in bundles, each of which consists of xylem, phloem, and sclerenchyma (strengthening tissue). Woody stems have an outer protective layer of tough bark, which is perforated with lenticels (pores) to allow gas exchange. Inside the bark is a ring of secondary phloem, which surrounds an inner core of secondary xylem.

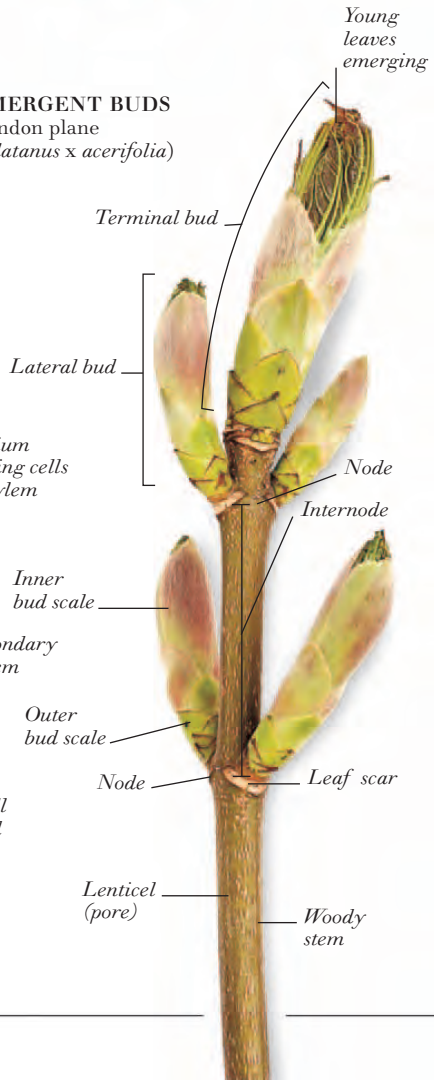
MICROGRAPH OF LONGITUDINAL SECTION THROUGH APEX OF STEM
Coleus sp.



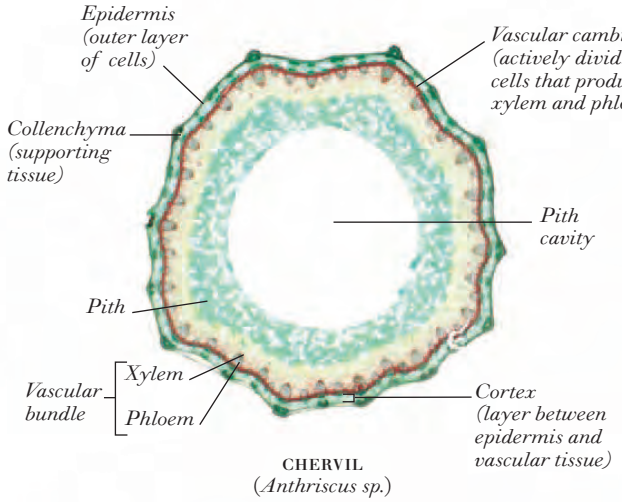
YOUNG WOODY STEM
Lime
(Tilia sp.)



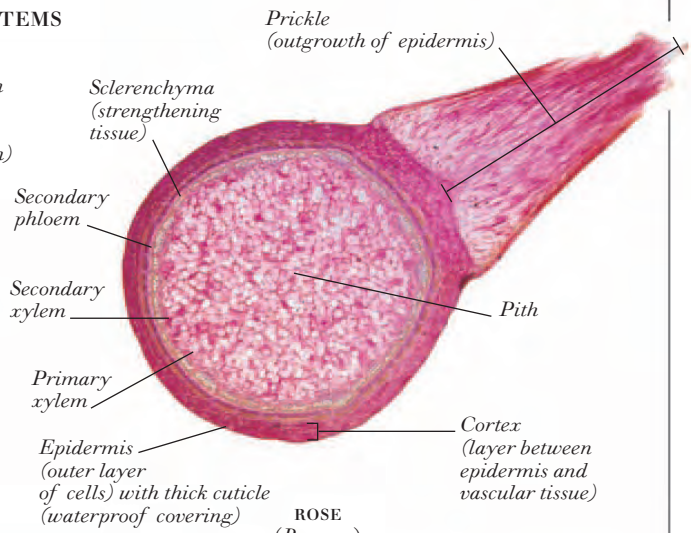
EMERGENT BUDS
London plane
(*Platanus* x *acerifolia*)



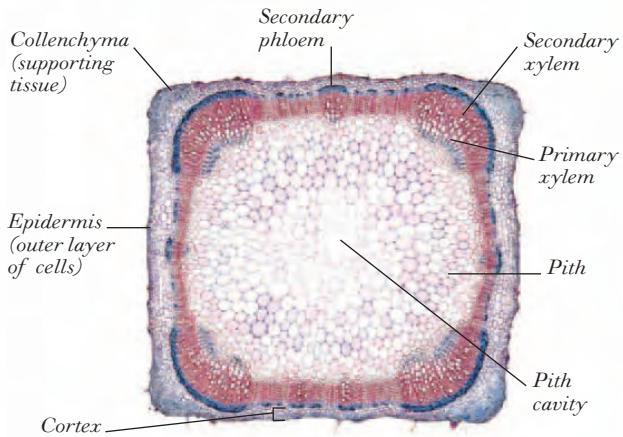
MICROGRAPHS OF CROSS-SECTIONS THROUGH VARIOUS STEMS



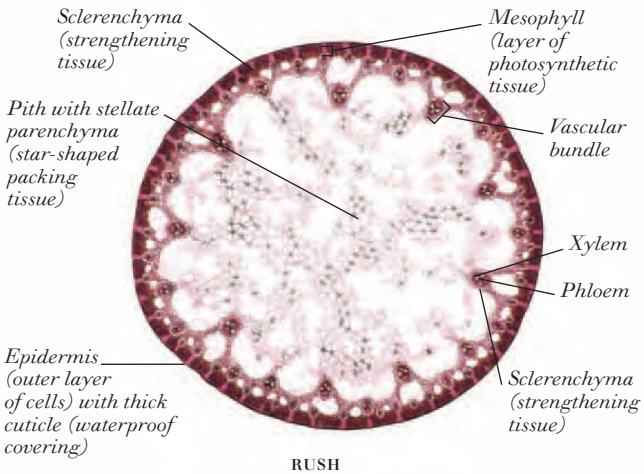
CHERVIL
(*Anthriscus sp.*)



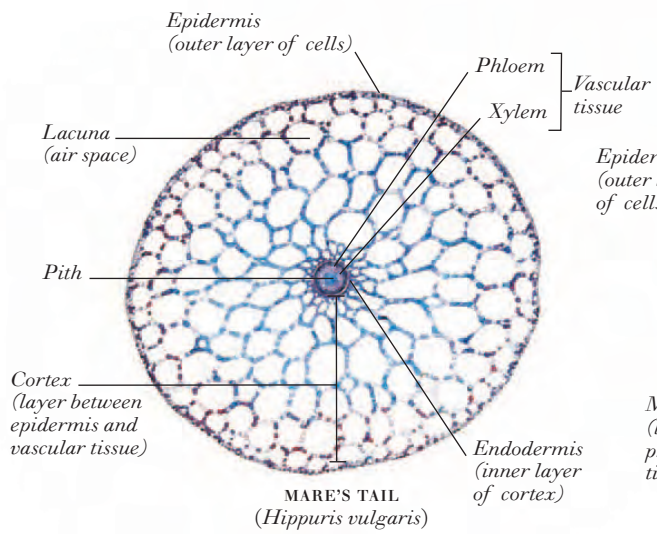
ROSE
(*Rosa sp.*)



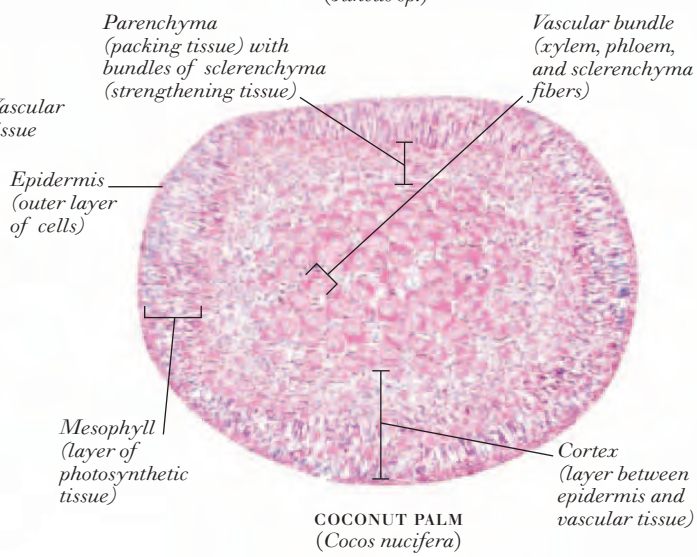
DEADNETTLE
(*Lamium sp.*)



RUSH
(*Juncus sp.*)



MARE'S TAIL
(*Hippuris vulgaris*)



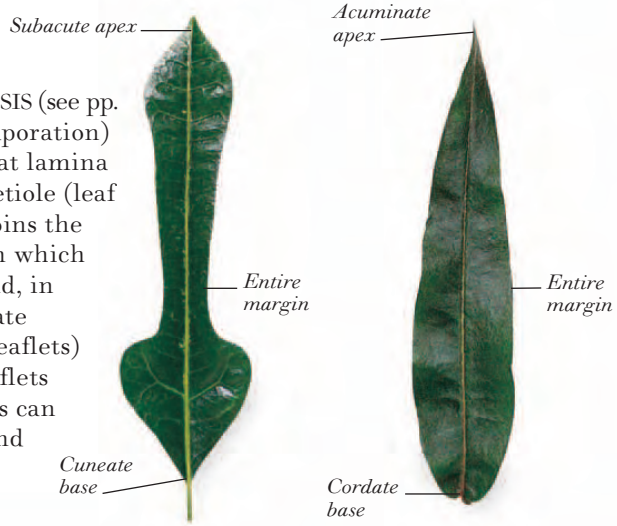
COCONUT PALM
(*Cocos nucifera*)

Leaves

CHECKERBLOOM
(Sidalcea malviflora)

LEAVES ARE THE MAIN SITES OF PHOTOSYNTHESIS (see pp. 138-139) and transpiration (water loss by evaporation) in plants. A typical leaf consists of a thin, flat lamina (blade) supported by a network of veins; a petiole (leaf stalk); and a leaf base, where the petiole joins the stem. Leaves can be classified as simple, in which the lamina is a single unit, or compound, in which the lamina is divided into separate leaflets. Compound leaves may be pinnate, with pinnae (leaflets) on both sides of a rachis (main axis), or palmate, with leaflets arising from a single point at the tip of the petiole. Leaves can be classified further by the overall shape of the lamina, and by the shape of the lamina's apex, margin, and base.

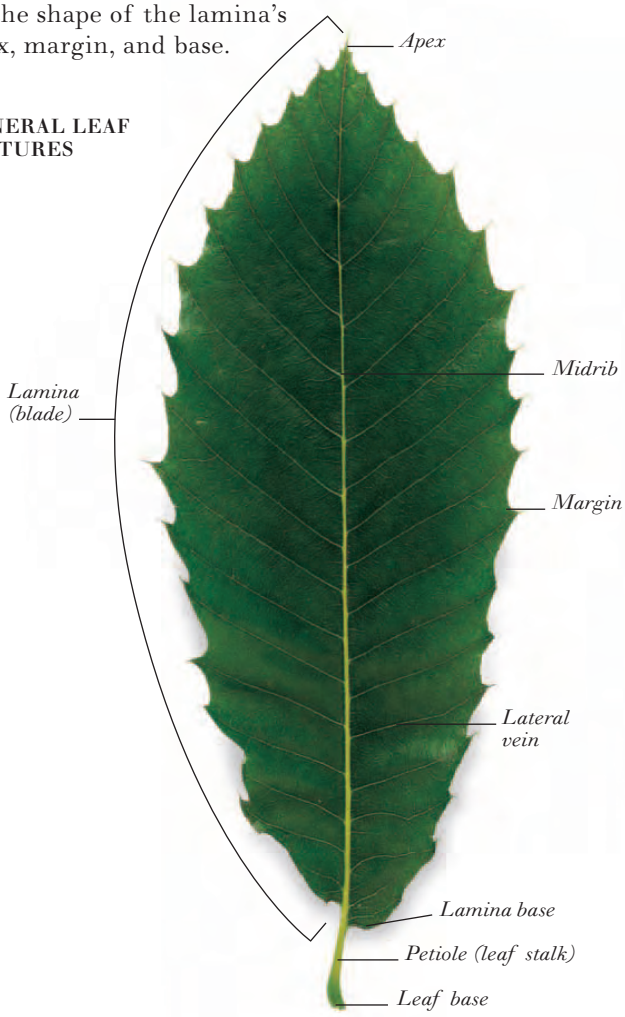
SIMPLE LEAF SHAPES



PANDURIFORM
Croton
(*Codiaeum variegatum*)

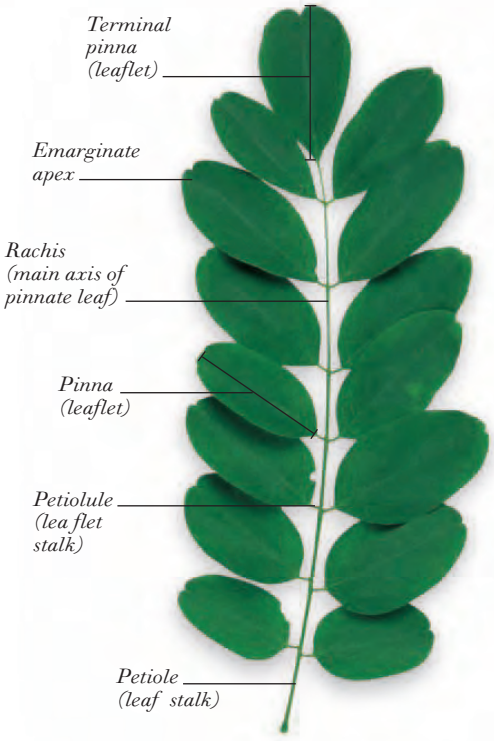
LANCEOLATE
Sea buckthorn
(*Hippophae rhamnoides*)

GENERAL LEAF FEATURES

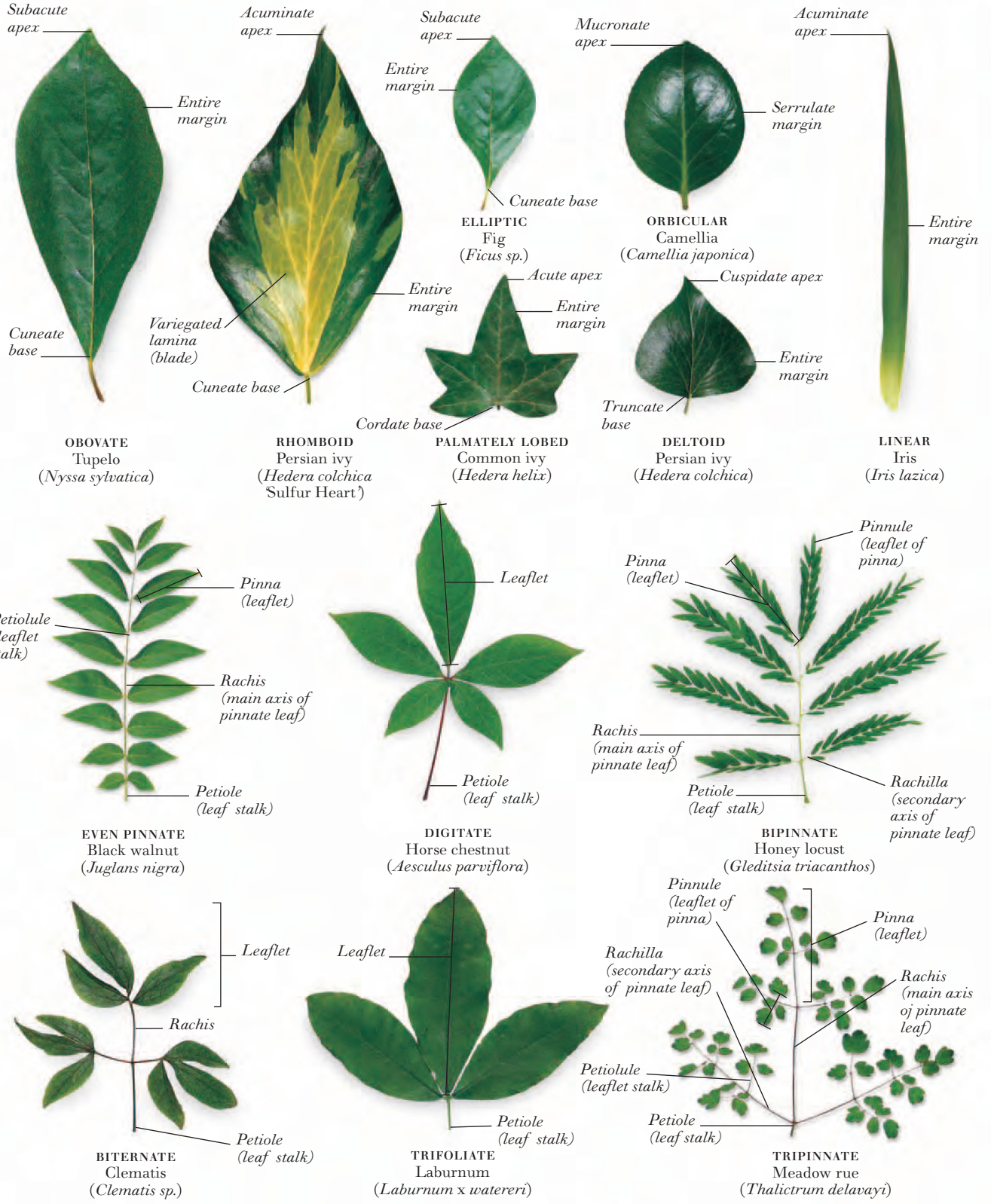


Sweet chestnut
(*Castanea sativa*)

COMPOUND LEAF SHAPES



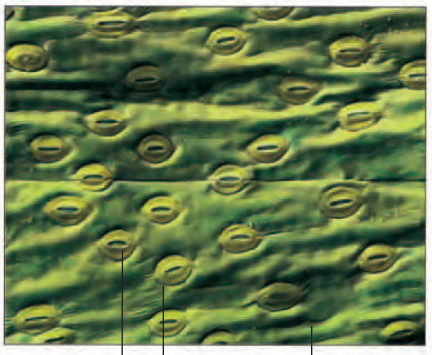
ODD PINNATE
False acacia
(*Robinia pseudoacacia*)


Subacute apex
Entire margin
Cuneate base
OBOVATE
Tupelo
(Nyssa sylvatica)
Acuminate apex
Entire margin
Variegated lamina (blade)
Cuneate base
RHOMBOID
Persian ivy
(Hedera colchica 'Sulfur Heart')
Subacute apex
Entire margin
Cuneate base
ELLIPTIC
Fig
(Ficus sp.)
Acute apex
Entire margin
Cordate base
PALMATELY LOBED
Common ivy
(Hedera helix)
Mucronate apex
Serrulate margin
ORBICULAR
Camellia
(Camellia japonica)
Cuspidate apex
Entire margin
Truncate base
DELTOID
Persian ivy
(Hedera colchica)
Acuminate apex
Entire margin
LINEAR
Iris
(Iris lazica)
Pinna (leaflet)
Petiolule (leaflet stalk)
Rachis (main axis of pinnate leaf)
Petiole (leaf stalk)
EVEN PINNATE
Black walnut
(Juglans nigra)
Leaflet
Petiole (leaf stalk)
DIGITATE
Horse chestnut
(Aesculus parviflora)
Pinnule (leaflet of pinna)
Pinna (leaflet)
Rachis (main axis of pinnate leaf)
Petiole (leaf stalk)
Rachilla (secondary axis of pinnate leaf)
BIPINNATE
Honey locust
(Gleditsia triacanthos)
Leaflet
Rachis
Petiole (leaf stalk)
BITERNATE
Clematis
(Clematis sp.)
Leaflet
Petiole (leaf stalk)
TRIFOLIATE
Laburnum
(Laburnum x watereri)
Pinnule (leaflet of pinna)
Pinna (leaflet)
Rachilla (secondary axis of pinnate leaf)
Rachis (main axis oj pinnate leaf)
Petiolule (leaflet stalk)
Petiole (leaf stalk)
TRIPINNATE
Meadow rue
(Thalictrum delavayi)

Photosynthesis

PHOTOSYNTHESIS IS THE PROCESS by which plants make their food using sunlight, water, and carbon dioxide. It takes place inside special structures in leaf cells called chloroplasts. The chloroplasts contain chlorophyll, a green pigment that absorbs energy from sunlight. During photosynthesis, the absorbed energy is used to join together carbon dioxide and water to form the sugar glucose, which is the energy source for the whole plant; oxygen, a waste product, is released into the air. Leaves are the main sites of photosynthesis, and have various adaptations for that purpose: flat laminae (blades) provide a large surface for absorbing sunlight; stomata (pores) in the lower surface of the laminae allow gases (carbon dioxide and oxygen) to pass into and out of the leaves; and an extensive network of veins brings water into the leaves and transports the glucose produced by photosynthesis to the rest of the plant.

MICROGRAPH OF LEAF
Lily (*Lilium sp.*)



Stoma (pore)

Guard cell (controls opening and closing of stoma)

Lower surface of lamina (blade)

THE PROCESS OF PHOTOSYNTHESIS

Glucose molecule

Oxygen atom

Carbon atom

Hydrogen atom

Glucose is a high-energy product of photosynthesis. It travels to all parts of the plant through the phloem

Sunlight, which is absorbed by chloroplasts in the leaf, provides the energy for photosynthesis

The leaf is the main site of photosynthesis. Its broad, thin lamina (blade) is an adaptation for this process

Hydrogen atom

Oxygen atom

Hydrogen atom

Water molecule

Carbon dioxide molecule

Oxygen atom

Carbon atom

Oxygen atom

Oxygen atom

Oxygen atom

Oxygen molecule

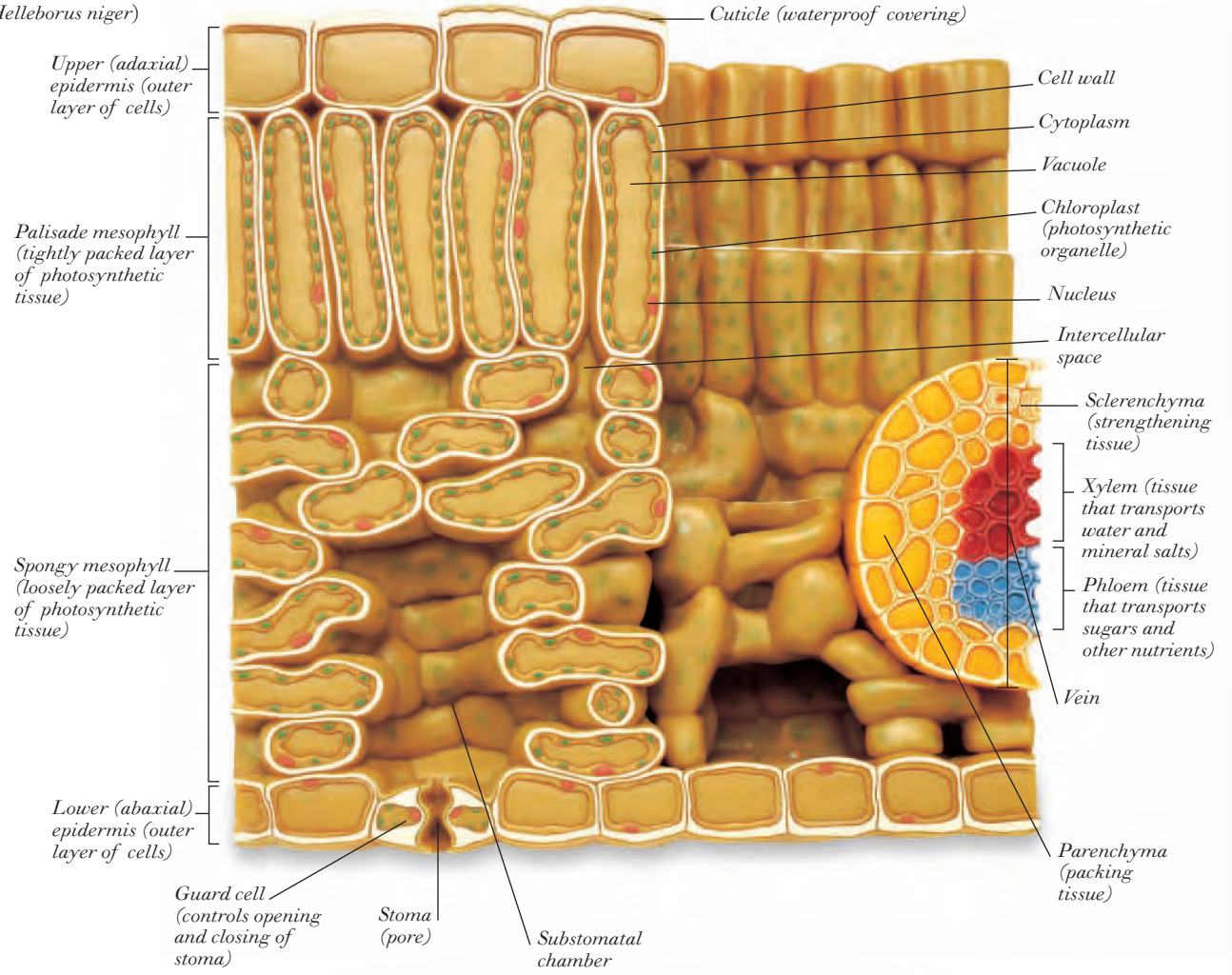
Water, a raw material in the soil, travels to the leaf from the roots via the xylem

Carbon dioxide, a raw material in the air, enters the leaf through stomata on the lower surface of the lamina (blade)

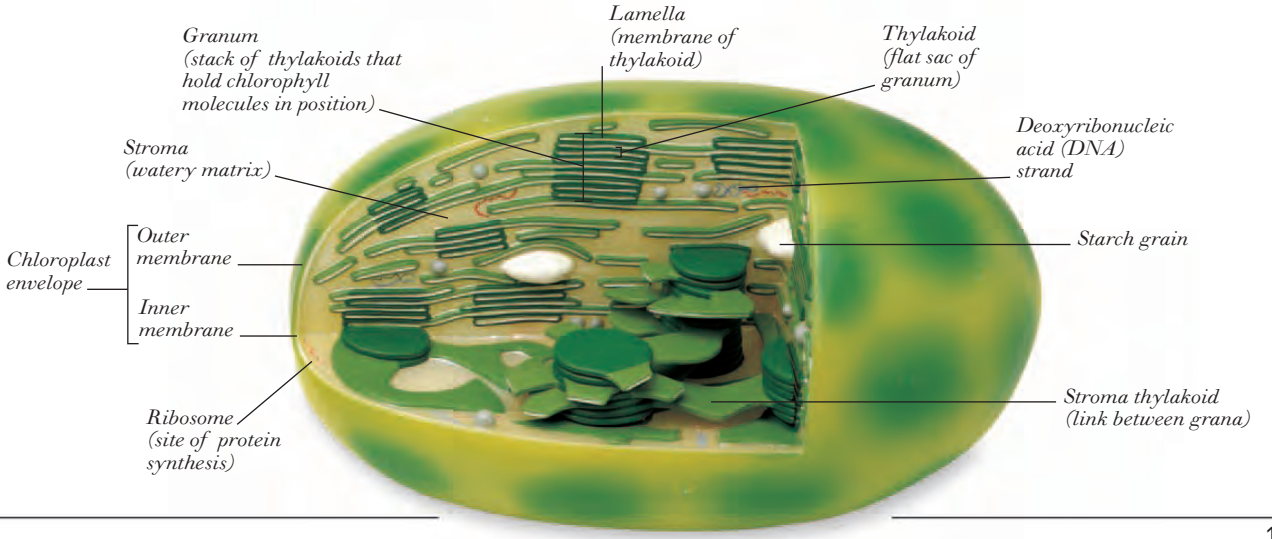
Oxygen, a waste product of photosynthesis, leaves the leaf through stomata on the lower surface of the lamina (blade)

CROSS-SECTION THROUGH LEAF

Christmas rose
(*Helleborus niger*)

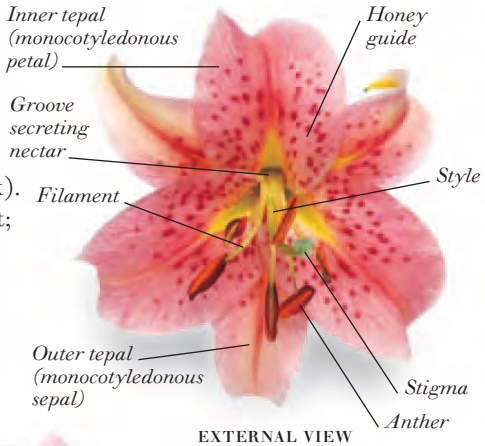


INTERNAL VIEW OF CHLOROPLAST



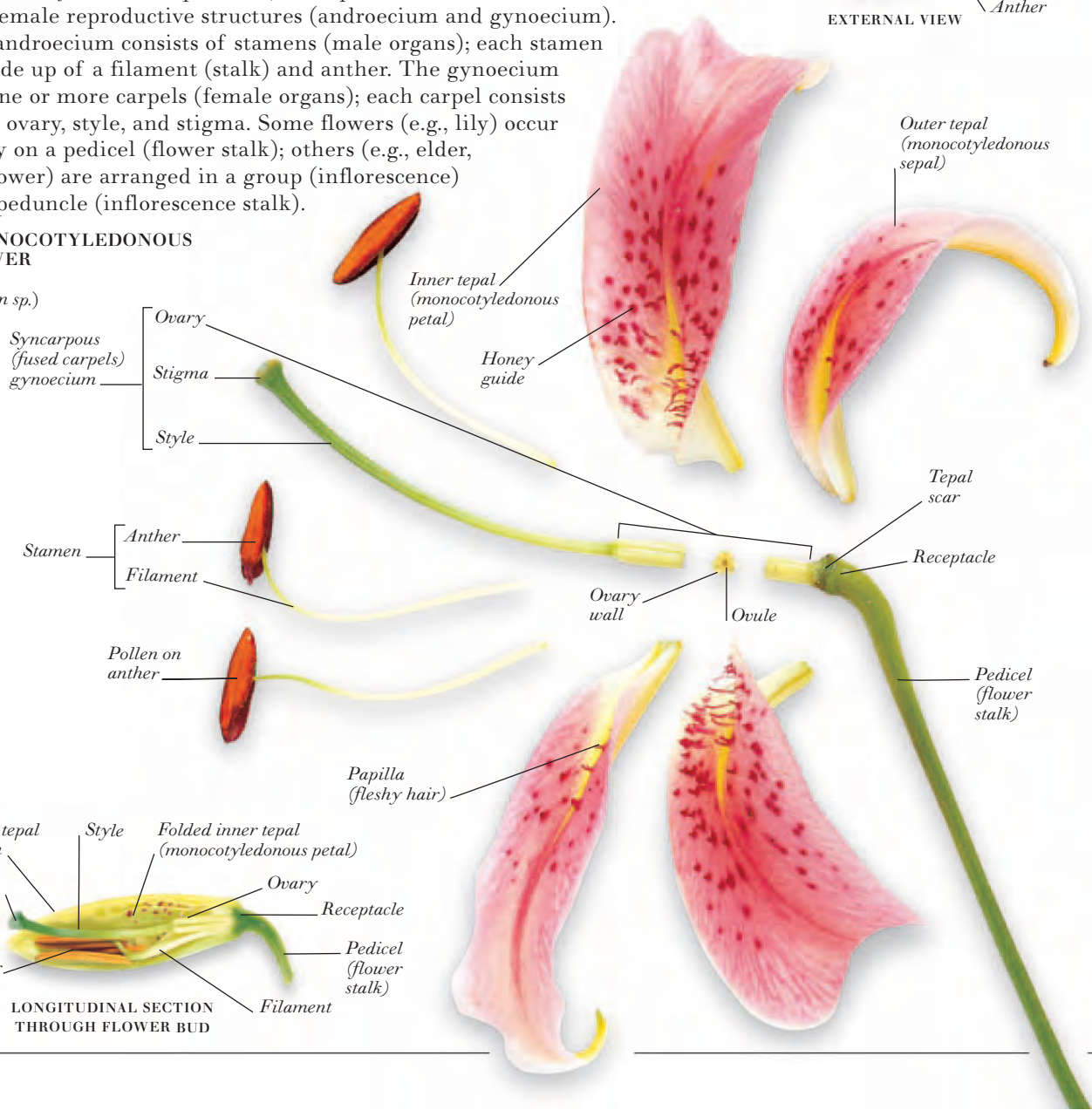
Flowers 1

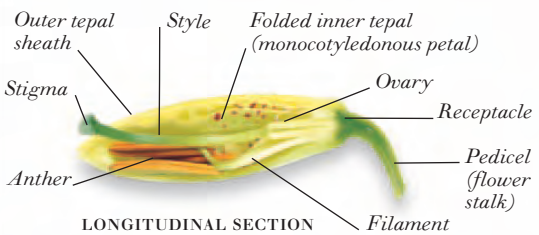
FLOWERS ARE THE SITES OF SEXUAL REPRODUCTION in flowering plants. Their component parts are arranged in whorls around the receptacle (tip of the flower stalk). The sepals (collectively called the calyx) are outermost; typically small and green, they protect the developing flower. The petals (collectively called the corolla) are typically large and brightly colored; they are found inside the sepals. In monocotyledonous flowers (see pp. 126-127), sepals and petals are indistinguishable; individually they are called tepals (collectively called the perianth). The petals surround the male and female reproductive structures (androecium and gynoecium). The androecium consists of stamens (male organs); each stamen is made up of a filament (stalk) and anther. The gynoecium has one or more carpels (female organs); each carpel consists of an ovary, style, and stigma. Some flowers (e.g., lily) occur singly on a pedicel (flower stalk); others (e.g., elder, sunflower) are arranged in a group (inflorescence) on a peduncle (inflorescence stalk).



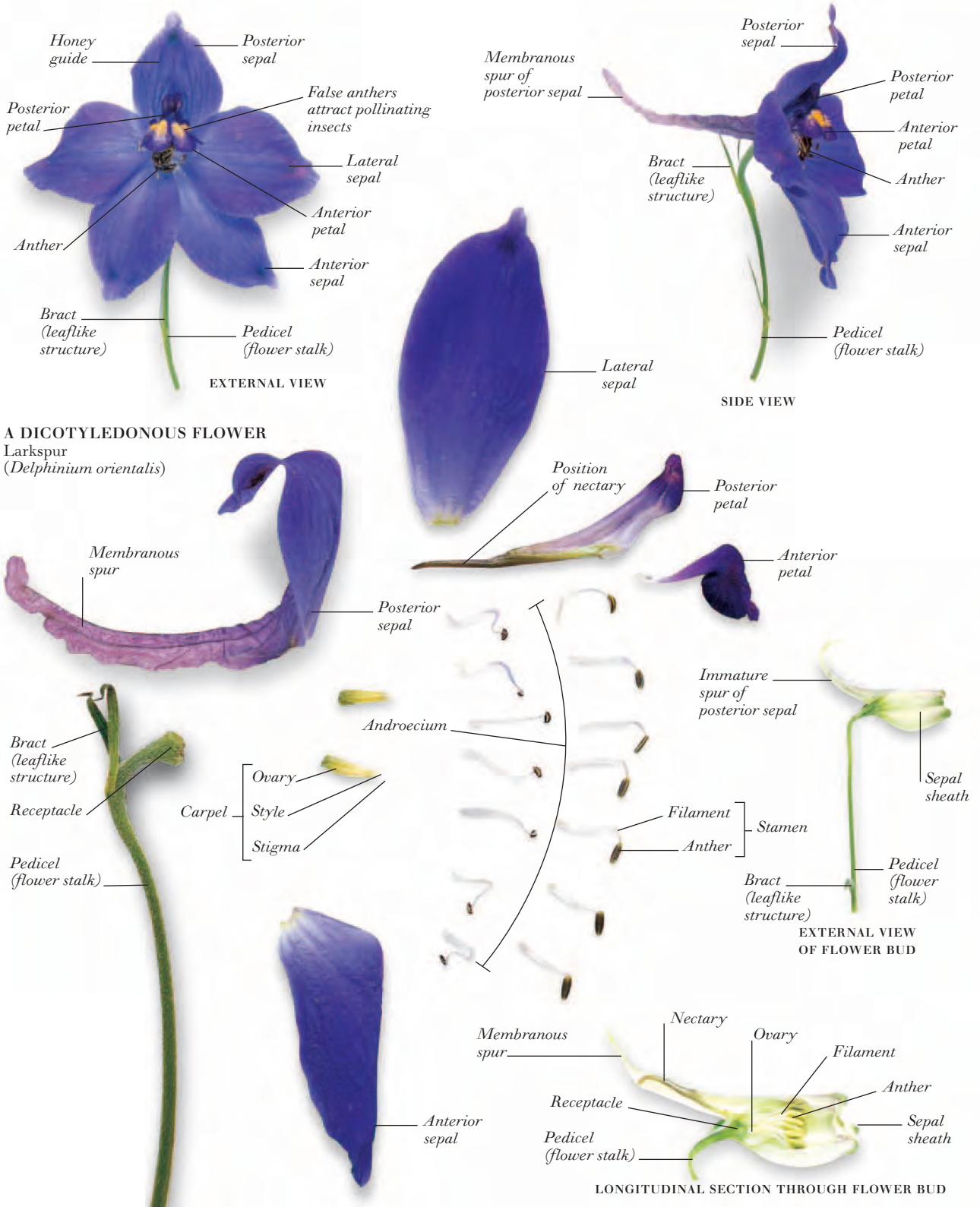
EXTERNAL VIEW

A MONOCOTYLEDONOUS FLOWER
Lily
(*Lilium sp.*)



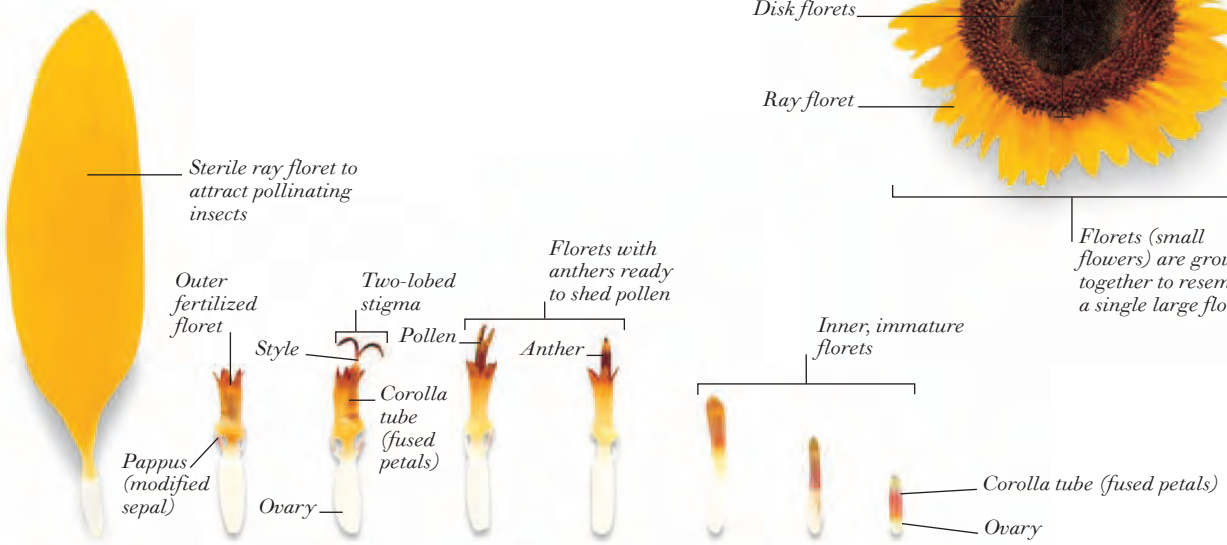


LONGITUDINAL SECTION THROUGH FLOWER BUD

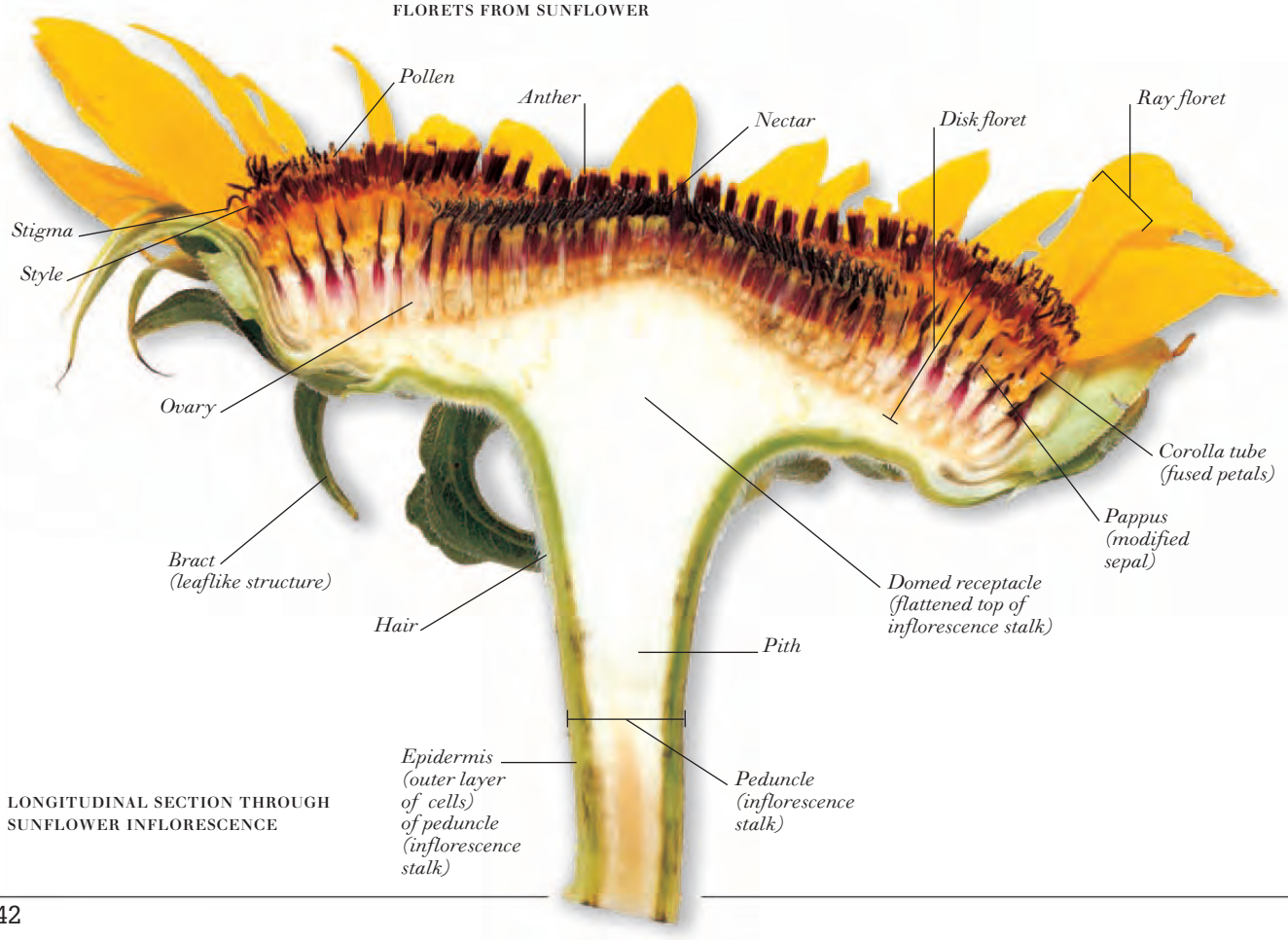

Honey guide
Posterior sepal
False anthers attract pollinating insects
Posterior petal
Lateral sepal
Anterior petal
Anther
Anterior sepal
Bract (leaflike structure)
Pedicel (flower stalk)
EXTERNAL VIEW
Membranous spur of posterior sepal
Posterior sepal
Posterior petal
Anterior petal
Bract (leaflike structure)
Anther
Anterior sepal
Pedicel (flower stalk)
SIDE VIEW
Lateral sepal
A DICOTYLEDONOUS FLOWER
Larkspur
(Delphinium orientalis)
Position of nectary
Posterior petal
Anterior petal
Membranous spur
Posterior sepal
Androecium
Immature spur of posterior sepal
Sepal sheath
Bract (leaflike structure)
Receptacle
Pedicel (flower stalk)
Carpel
Ovary
Style
Stigma
Filament
Anther
Stamen
Bract (leaflike structure)
Pedicel (flower stalk)
EXTERNAL VIEW OF FLOWER BUD
Anterior sepal
Membranous spur
Nectary
Ovary
Filament
Anther
Receptacle
Sepal sheath
Pedicel (flower stalk)
LONGITUDINAL SECTION THROUGH FLOWER BUD

Flowers 2

COMPOUND INFLORESCENCE
(CAPITULUM)
Sunflower
(*Helianthus annulus*)

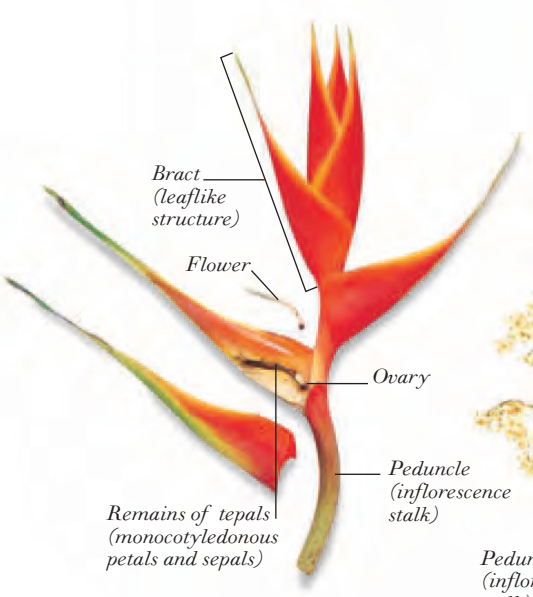


FLORETS FROM SUNFLOWER

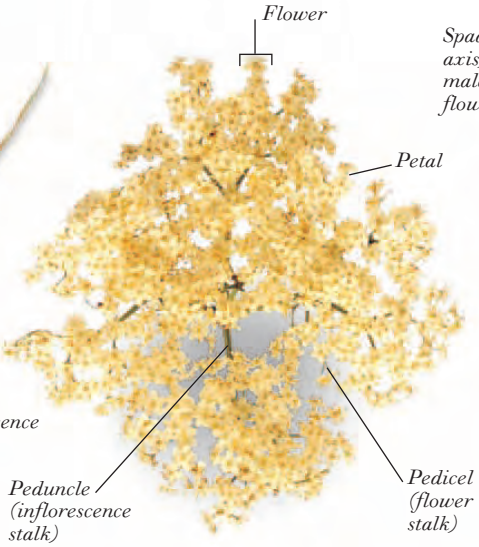


LONGITUDINAL SECTION THROUGH SUNFLOWER INFLORESCENCE

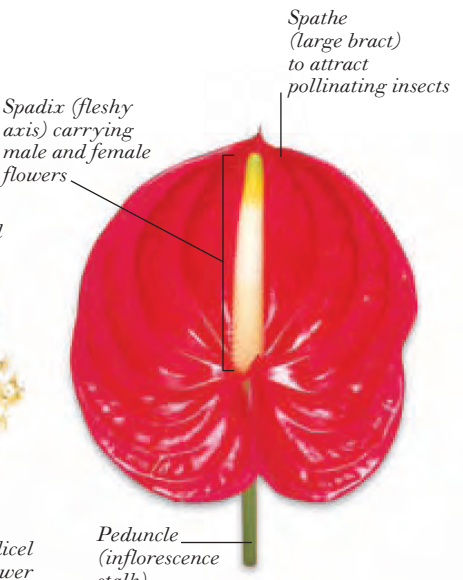
ARRANGEMENT OF FLOWERS ON STEM



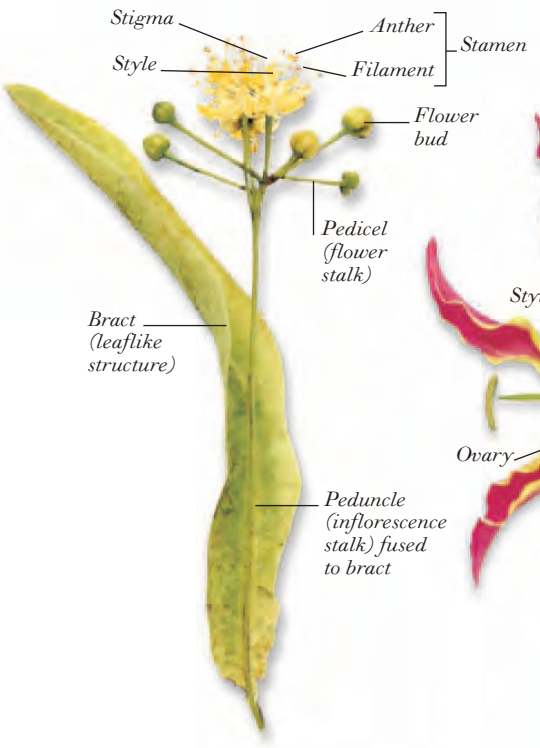
INFLORESCENCE (SPIKE)
Heliconia peruviana



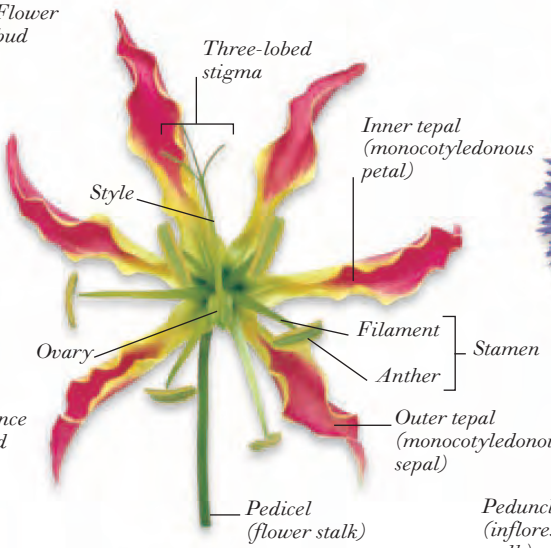
INFLORESCENCE (COMPOUND UMBEL)
Common elder
(*Sambucus nigra*)



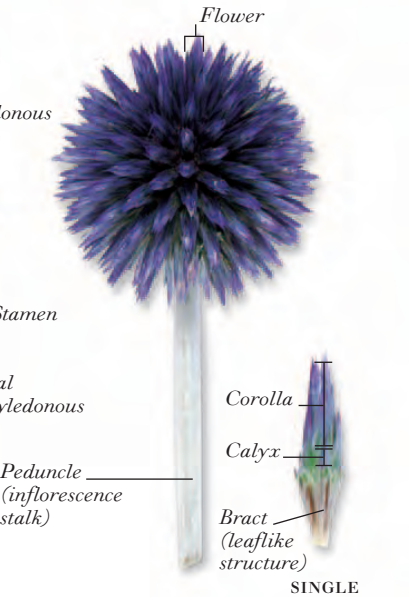
INFLORESCENCE (SPADIX)
Painter's palette
(*Anthurium andreanum*)



INFLORESCENCE (DICHASIAL CYME)
Common lime
(*Tilia* x *europaea*)



SINGLE FLOWER
Glory lily
(*Gloriosa superba*)



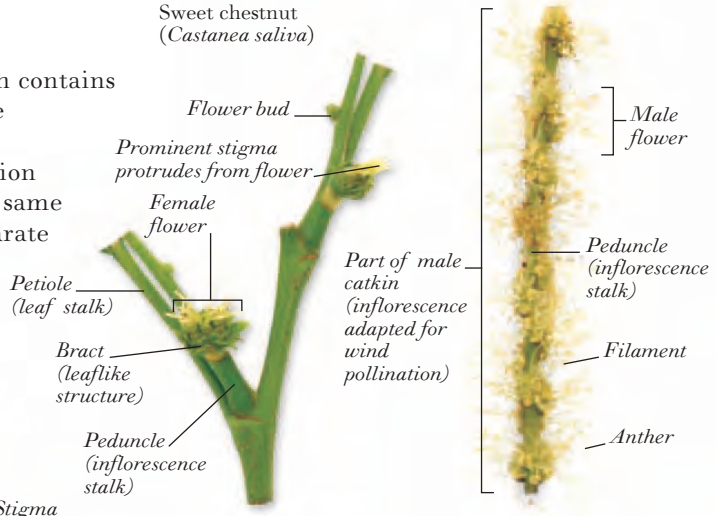
SINGLE FLOWER

INFLORESCENCE (SPHERICAL UMBEL)
Allium sp.

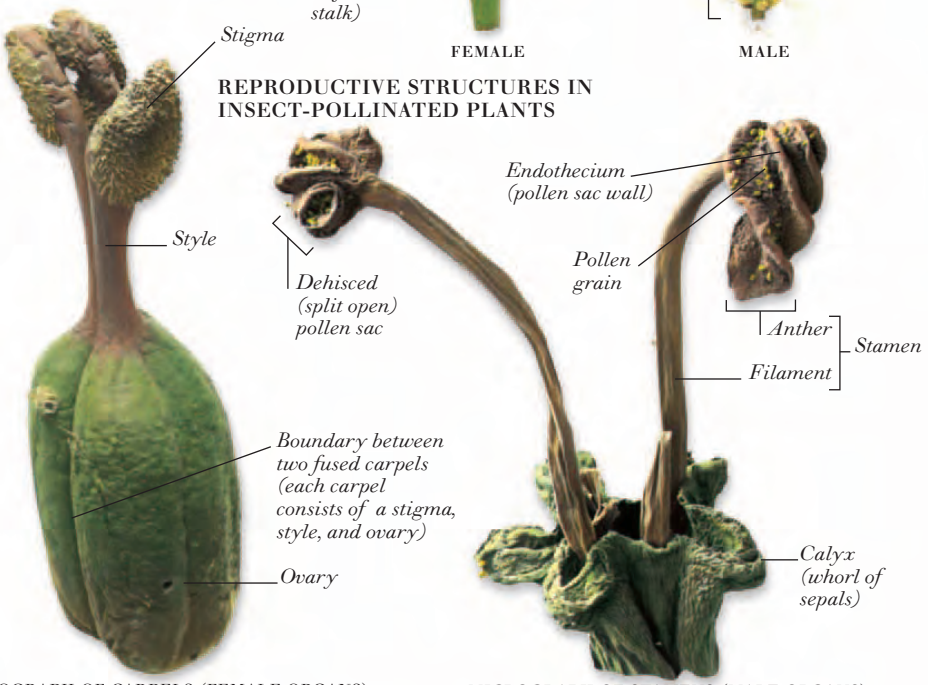
Pollination

POLLINATION IS THE TRANSFER OF POLLEN (which contains the male sex cells) from an anther (part of the male reproductive organ) to a stigma (part of the female reproductive organ). This process precedes fertilization (see pp. 146-147). Pollination may occur within the same flower (self-pollination), or between flowers on separate plants of the same species (cross-pollination). In most plants, pollination is carried out either by insects (entomophilous pollination) or by the wind (anemophilous pollination). Less commonly, birds, bats, or water are the agents of pollination. Insect-pollinated flowers are typically brightly colored, scented, and produce nectar, on which insects feed. Such flowers also tend to have patterns that are visible only in ultraviolet light, which many insects can see but which humans cannot. These features attract insects, which become covered with the sticky or hooked pollen grains when they visit one flower, and then transfer the pollen to the next flower they visit. Wind-pollinated flowers are generally small, relatively inconspicuous, and unscented. They produce large quantities of light pollen grains that are easily blown by the wind to other flowers.

REPRODUCTIVE STRUCTURES IN WIND-POLLINATED PLANT
Sweet chestnut
(*Castanea saliva*)



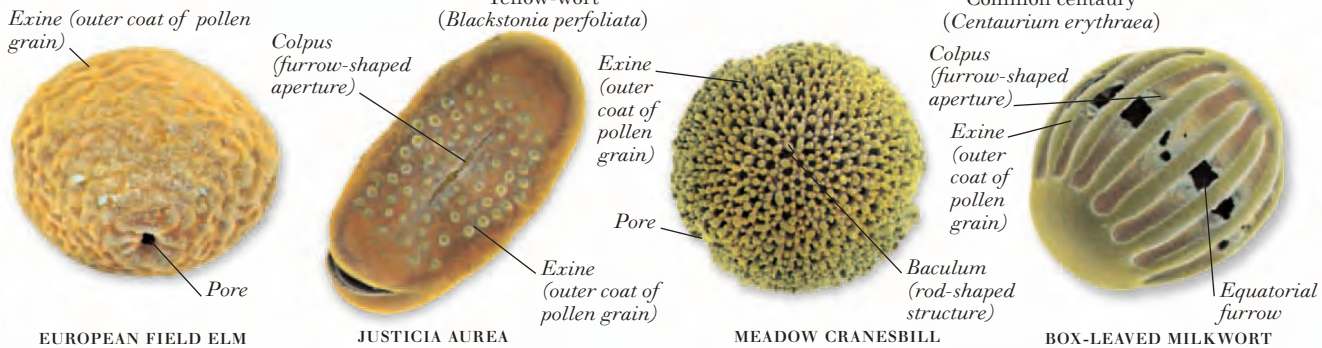
REPRODUCTIVE STRUCTURES IN INSECT-POLLINATED PLANTS



MICROGRAPH OF CARPELS (FEMALE ORGANS)
Yellow-wort
(*Blackstonia perfoliata*)

MICROGRAPH OF STAMENS (MALE ORGANS)
Common centaury
(*Centaurium erythraea*)

MICROGRAPHS OF POLLEN GRAINS



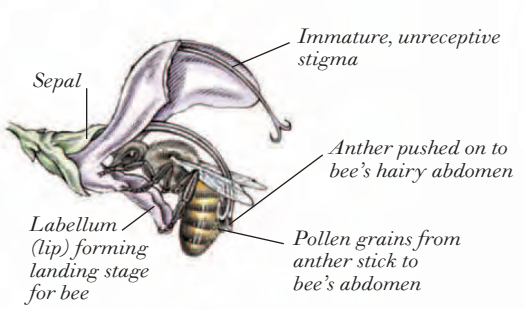
EUROPEAN FIELD ELM
(*Ulmus minor*)

JUSTICIA AUREA

MEADOW CRANESBILL
(*Geranium pratense*)

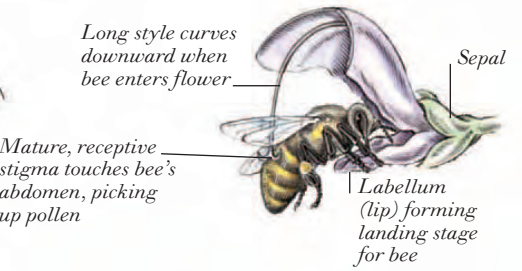
BOX-LEAVED MILKWORT
(*Polygala chamaebuxus*)

INSECT POLLINATION OF MEADOW SAGE



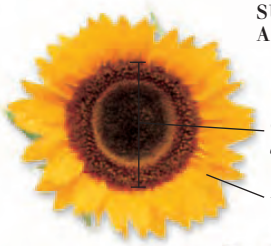
1. BEE VISITS FLOWER WITH MATURE ANTHERS BUT IMMATURE STIGMA

2. BEE FLIES TO OTHER FLOWERS



3. BEE VISITS FLOWER WHERE THE ANTHERS HAVE WITHERED AND THE STIGMA IS MATURE

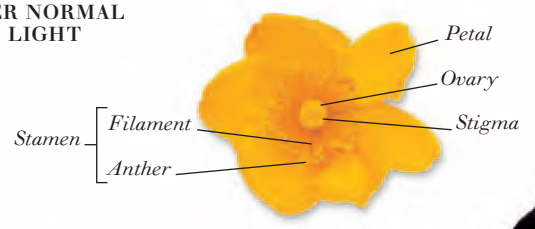
SUNFLOWER UNDER NORMAL AND ULTRAVIOLET LIGHT



NORMAL LIGHT

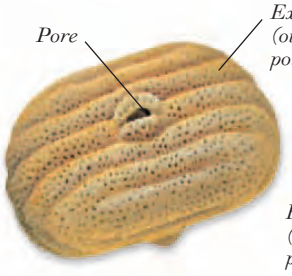
ULTRAVIOLET LIGHT

ST. JOHN'S WORT UNDER NORMAL AND ULTRAVIOLET LIGHT

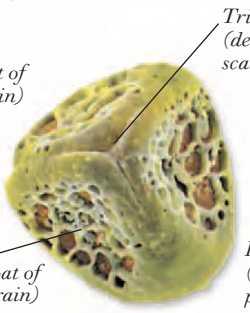


NORMAL LIGHT

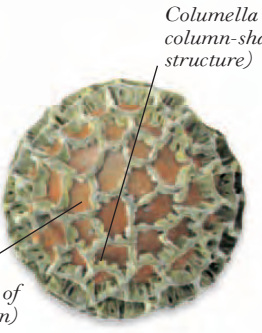
ULTRAVIOLET LIGHT



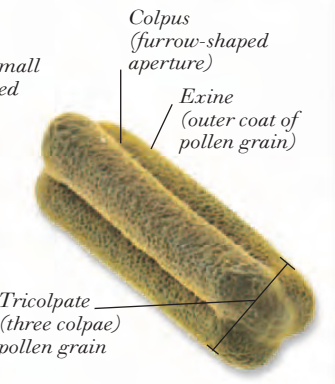
MIMULOPSIS SOLMSII



THESIUM ALPINIUM



RUELLIA GRANDIFLORA



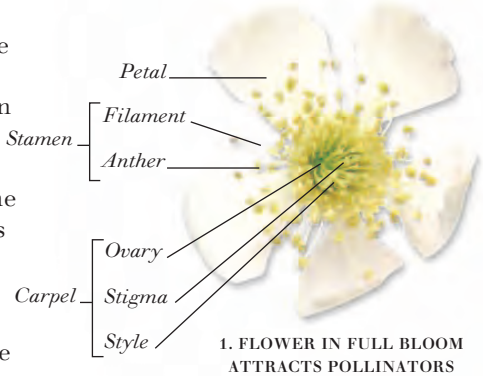
CROSSANDRA NILOTICA

Fertilization

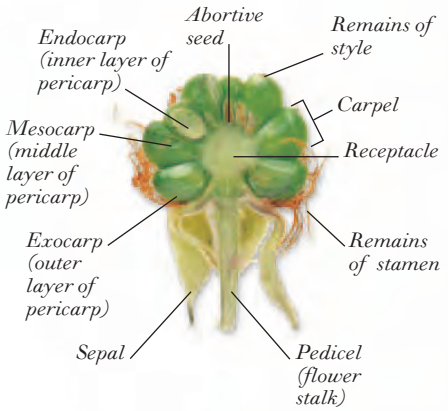
BANANA
(*Musa 'lacatan'*)

FERTILIZATION IS THE FUSION of male and female gametes (sex cells) to produce a zygote (embryo). Following pollination (see pp. 144-145), the pollen grains that contain the male gametes are on the stigma, some distance from the female gamete (ovum) inside the ovule. To enable the gametes to meet, the pollen grain germinates and produces a pollen tube, which grows down and enters the embryo sac (the inner part of the ovule that contains the ovum). Two male gametes, traveling at the tip of the pollen tube, enter the embryo sac. One gamete fuses with the ovum to produce a zygote that will develop into an embryo plant. The other male gamete fuses with two polar nuclei to produce the endosperm, which acts as a food supply for the developing embryo. Fertilization also initiates other changes: the integument (outer part of ovule) forms a testa (seed coat) around the embryo and endosperm; the petals fall off; the stigma and style wither; and the ovary wall forms a layer (called the pericarp) around the seed. Together, the pericarp and seed form the fruit, which may be succulent (see pp. 148-149) or dry (see pp. 150-151). In some species (e.g., blackberry), apomixis can occur: the seed develops without fertilization of the ovum by a male gamete but endosperm formation and fruit development take place as in other species.

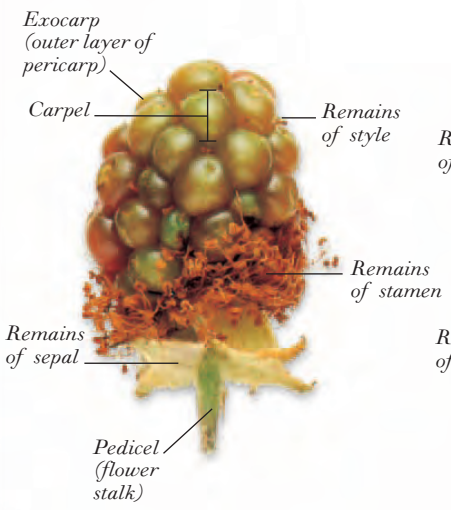
DEVELOPMENT OF A SUCCULENT FRUIT
Blackberry
(*Rubus fruticosus*)



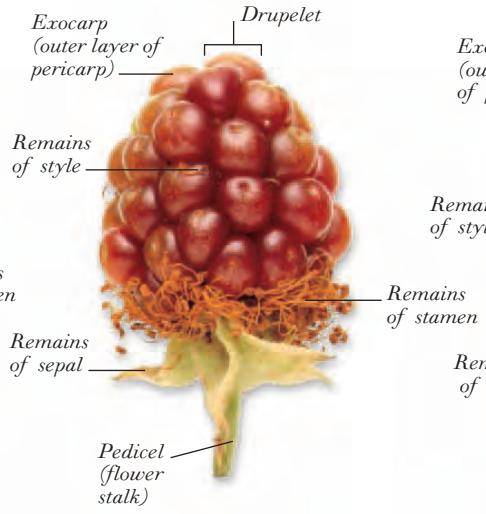
1. FLOWER IN FULL BLOOM ATTRACTS POLLINATORS



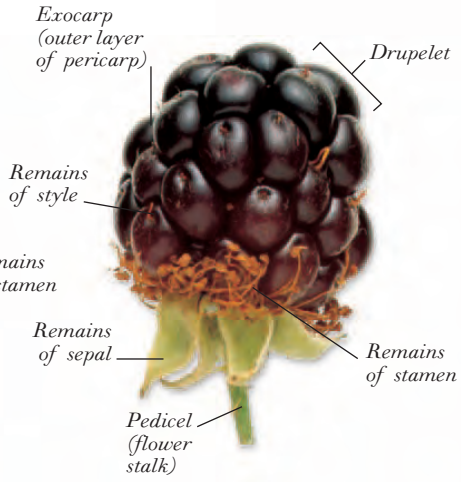
4. PERICARP FORMS FLESH, SKIN, AND A HARD INNER LAYER (SHOWN IN CROSS-SECTION)



7. MESOCARP (FLESHY PART OF PERICARP) OF EACH CARPEL STARTS TO CHANGE COLOR

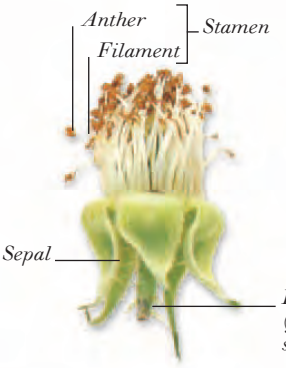


8. CARPELS MATURE INTO DRUPELETS (SMALL FLESHY FRUITS WITH SINGLE SEEDS SURROUNDED BY HARD ENDOCARP)

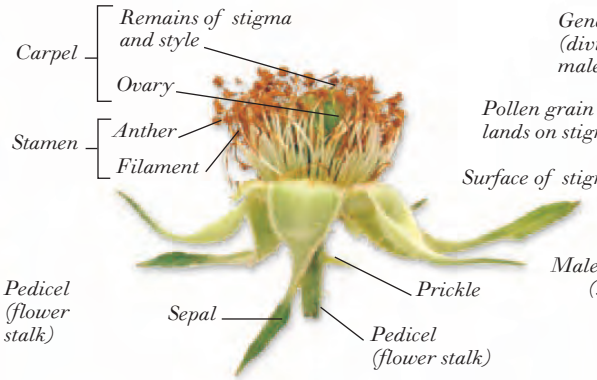


9. MESOCARP OF DRUPELET BECOMES DARKER AND SWEETER

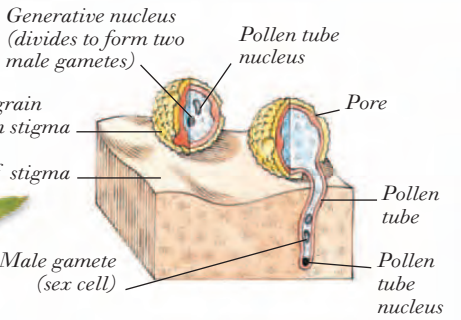
THE PROCESS OF FERTILIZATION



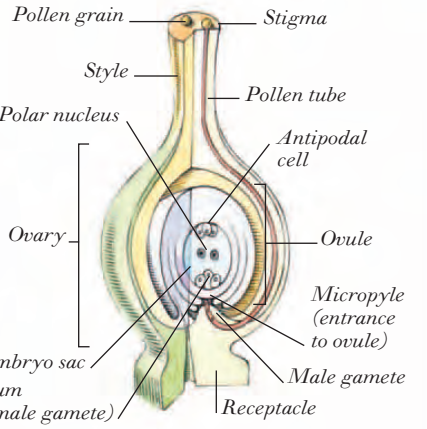
2. FERTILIZATION HAS TAKEN PLACE; PETALS FALL OFF



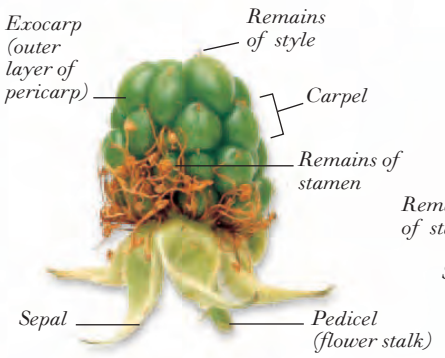
3. OVARIES BEGIN TO SWELL; STAMENS WITHER AND DIE



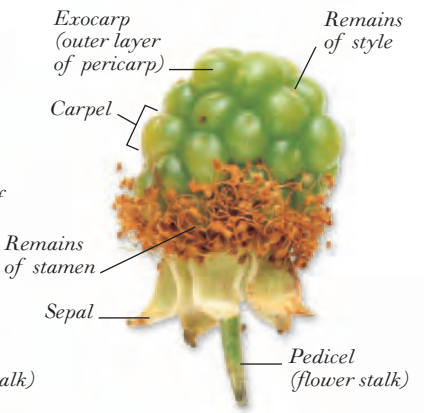
POLLEN GRAIN GERMINATES



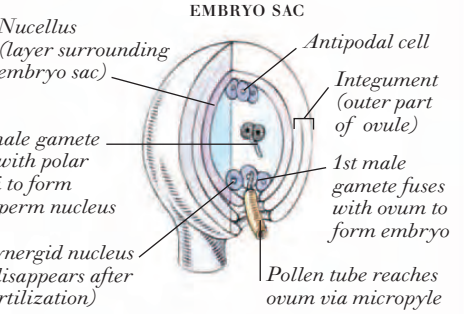
MALE GAMETES TRAVEL TO EMBRYO SAC



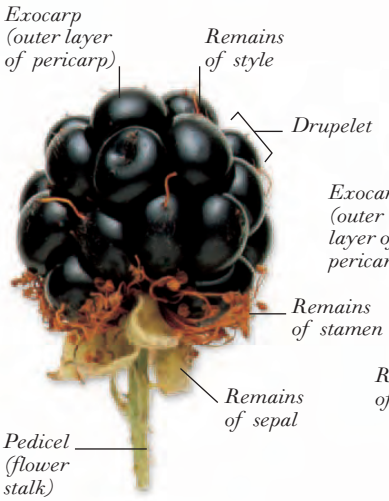
5. CARPELS EXPAND AND BECOME MORE FLESHY



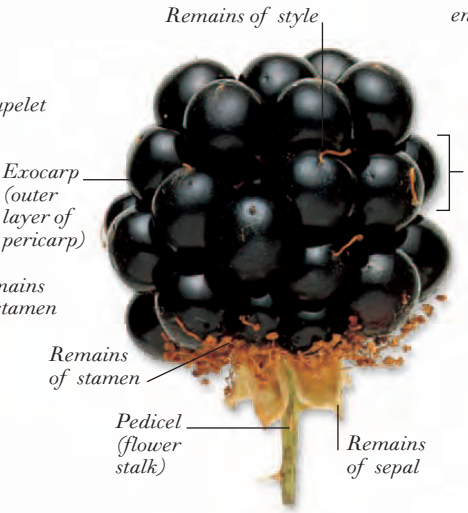
6. CARPELS EXPAND FURTHER



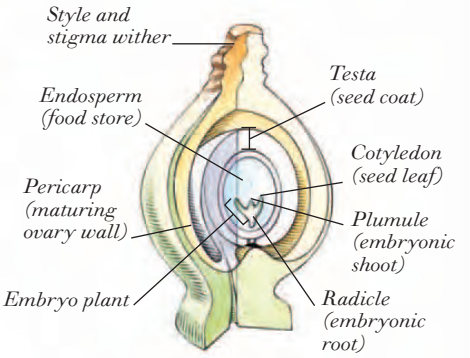
FERTILIZATION



10. DRUPELETS (COLLECTIVELY AN AGGREGATE FRUIT) EXPAND



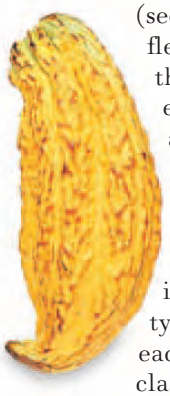
11. DRUPELETS RIPEN FULLY



DEVELOPMENT OF EMBRYO

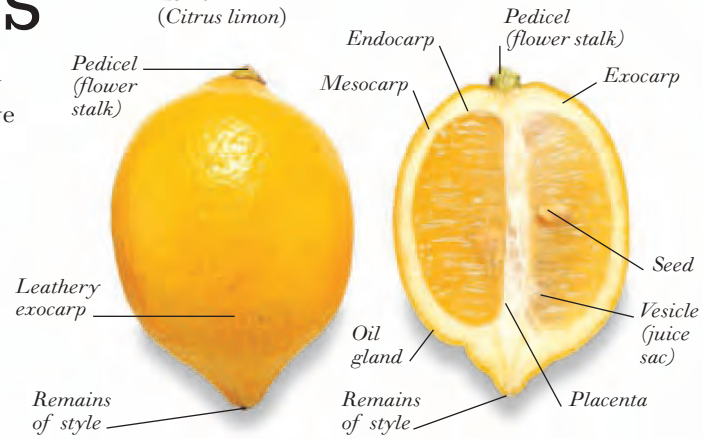
Succulent fruits

A FRUIT IS A FULLY DEVELOPED and ripened ovary (seed-producing part of a plant's female reproductive organs). Fruits may be succulent or dry (see pp. 150-151). Succulent fruits are fleshy and brightly colored, making them attractive to animals, which eat them and so disperse the seeds away from the parent plant. The wall (pericarp) of a succulent fruit has three layers: an outer exocarp, a middle mesocarp, and an inner endocarp. These three layers vary in thickness and texture in different types of fruits and may blend into each other. Succulent fruits can be classed as simple (derived from one ovary) or compound (derived from several ovaries). Simple succulent fruits include berries, which typically have many seeds, and drupes, which typically have a single stone or pit (e.g., cherry and peach). Compound succulent fruits include aggregate fruits, which are formed from many ovaries in one flower, and multiple fruits, which develop from the ovaries of many flowers. Some fruits, known as false fruits or pseudocarps, develop from parts of the flower in addition to the ovaries. For example, the flesh of the apple is formed from the receptacle (the upper end of the flower stalk).



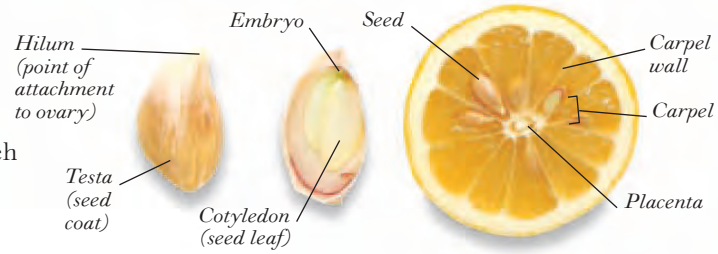
BERRY
Cocoa
(*Theobroma cacao*)

HESPERIDIUM (A TYPE OF BERRY)
Lemon
(*Citrus limon*)



EXTERNAL VIEW OF FRUIT

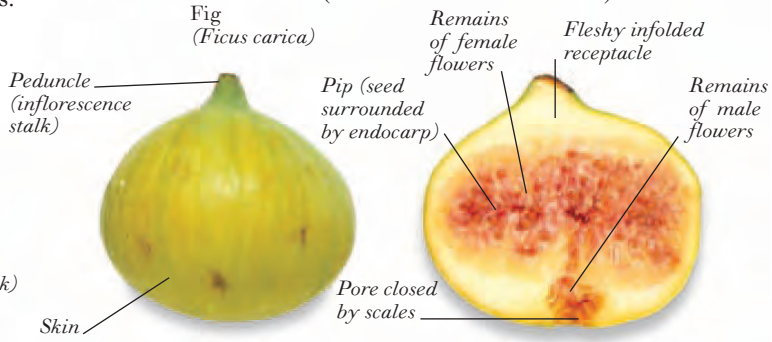
LONGITUDINAL SECTION THROUGH FRUIT



EXTERNAL VIEW AND SECTION THROUGH SEED

CROSS-SECTION THROUGH FRUIT

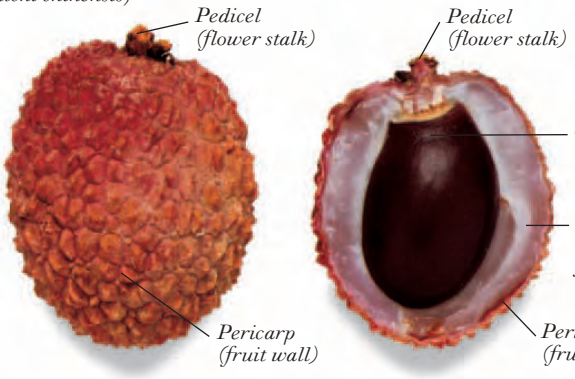
SYCONIUM (A TYPE OF FALSE FRUIT)
Fig
(*Ficus carica*)



EXTERNAL VIEW OF FRUIT

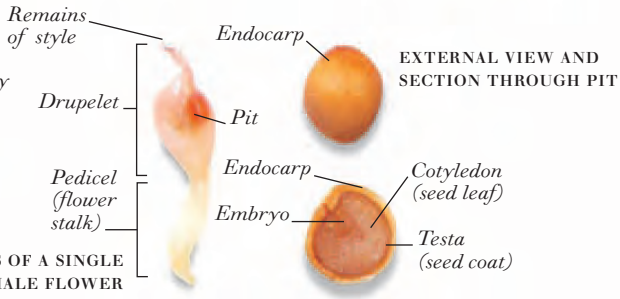
LONGITUDINAL SECTION THROUGH FRUIT

FRUIT WITH FLESHY ARIL
Lychee
(*Litchi chinensis*)



EXTERNAL VIEW OF FRUIT

LONGITUDINAL SECTION THROUGH FRUIT

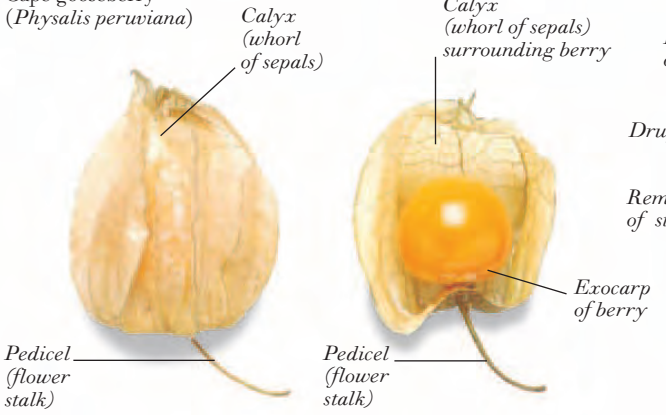


REMAINS OF A SINGLE FEMALE FLOWER

EXTERNAL VIEW AND SECTION THROUGH PIT

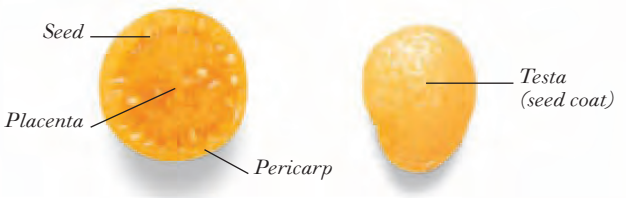
BERRY

Cape gooseberry
(*Physalis peruviana*)



EXTERNAL VIEW OF FRUIT

INTERNAL VIEW OF FRUIT

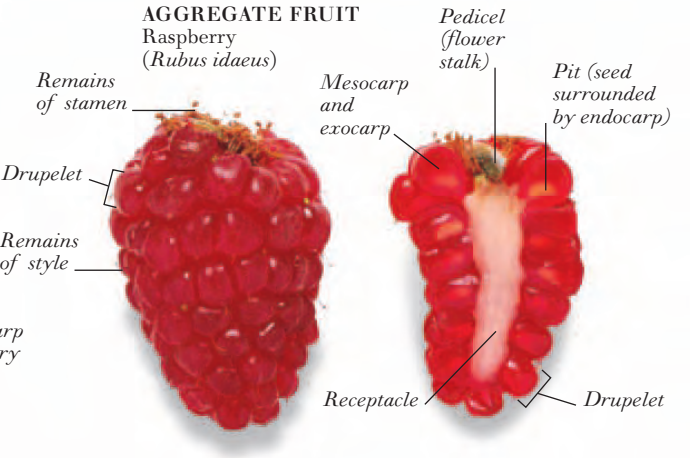


CROSS-SECTION THROUGH FRUIT

EXTERNAL VIEW OF SEED

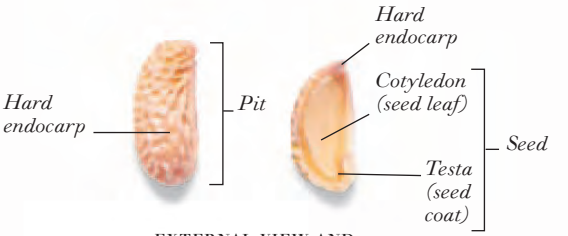
AGGREGATE FRUIT

Raspberry
(*Rubus idaeus*)



EXTERNAL VIEW OF FRUIT

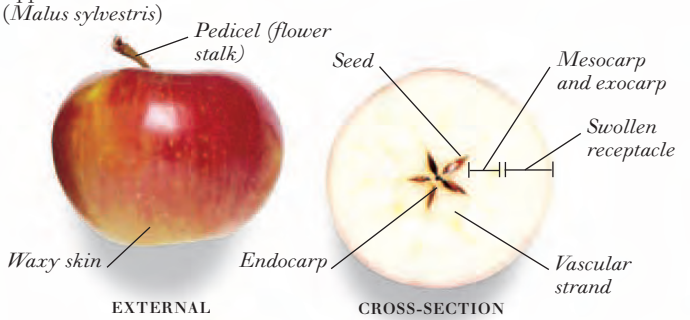
LONGITUDINAL SECTION THROUGH FRUIT



EXTERNAL VIEW AND SECTION THROUGH PIT

POME (A TYPE OF FALSE FRUIT)

Apple
(*Malus sylvestris*)



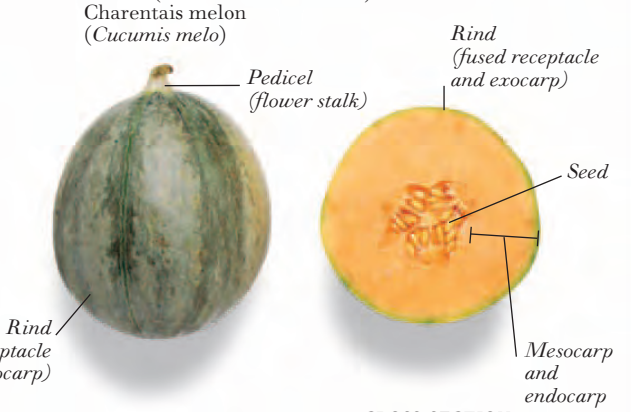
EXTERNAL VIEW OF FRUIT

CROSS-SECTION THROUGH FRUIT

EXTERNAL VIEW AND SECTION THROUGH SEED

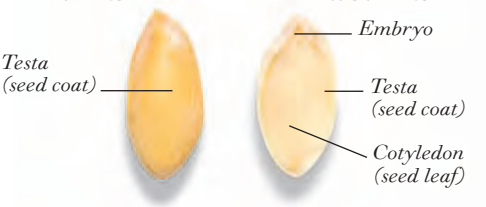
PEPO (A TYPE OF BERRY)

Charentais melon
(*Cucumis melo*)



EXTERNAL VIEW OF FRUIT

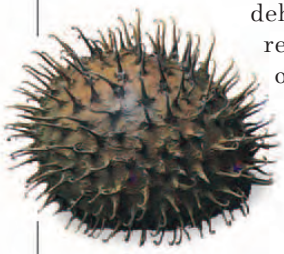
CROSS-SECTION THROUGH FRUIT



EXTERNAL VIEW AND SECTION THROUGH SEED

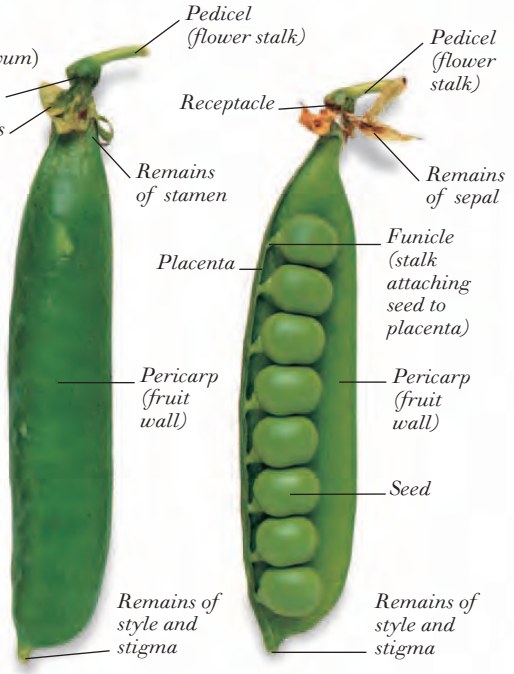
Dry fruits

DRY FRUITS HAVE A HARD, DRY PERICARP (fruit wall) around their seeds unlike succulent fruits, which have fleshy pericarps (see pp. 148-149). Dry fruits are divided into three types: dehiscent, in which the pericarp splits open to release the seeds; indehiscent, which do not split open; and schizocarpic, in which the fruit splits but the seeds are not exposed. Dehiscent dry fruits include capsules (e.g., love-in-a-mist), follicles (e.g., delphinium), legumes (e.g., pea), and siliquas (e.g., honesty). Typically, the seeds of dehiscent fruits are dispersed by the wind. Indehiscent dry fruits include nuts (e.g., sweet chestnut), nutlets (e.g., goosegrass), achenes (e.g., strawberry), caryopses (e.g., wheat), samaras (e.g., elm), and cypselas (e.g., dandelion). Some indehiscent dry fruits are dispersed by the wind, assisted by "wings" (e.g., elm) or "parachutes" (e.g., dandelion); others (e.g., goosegrass) have hooked pericarps to aid dispersal on animals' fur. Schizocarpic dry fruits include cremocarps (e.g., hogweed), and double samaras (e.g., sycamore maple); these are dispersed by the wind.



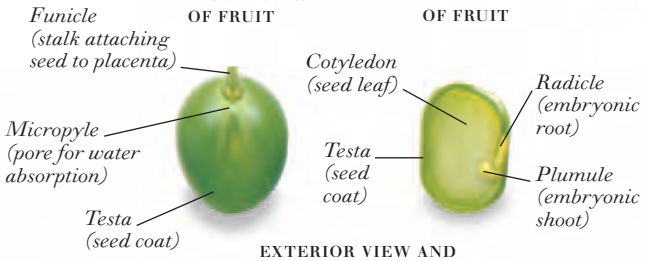
NUTLET
Goosegrass
(*Galium aparine*)

LEGUME
Pea
(*Pisum sativum*)



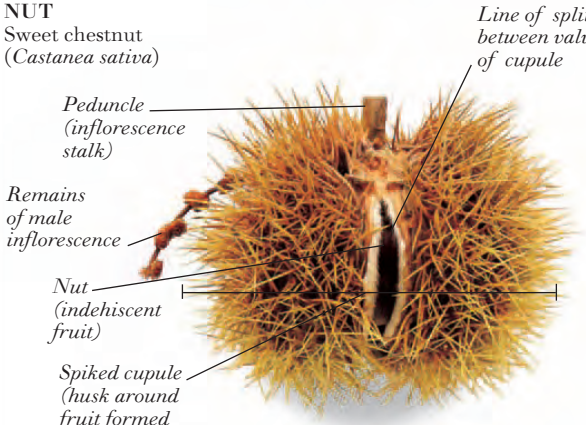
EXTERNAL VIEW OF FRUIT

INTERNAL VIEW OF FRUIT



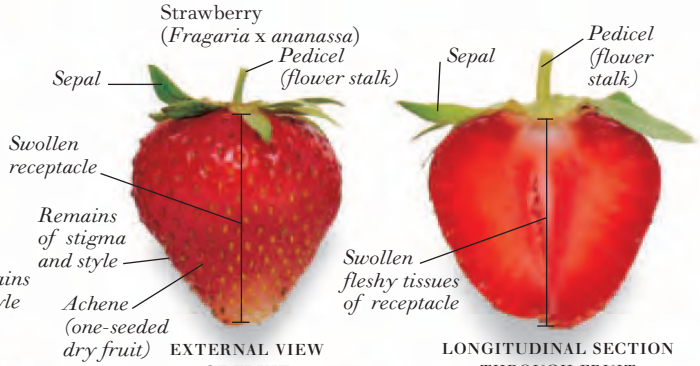
EXTERIOR VIEW AND SECTION THROUGH SEED

NUT
Sweet chestnut
(*Castanea sativa*)



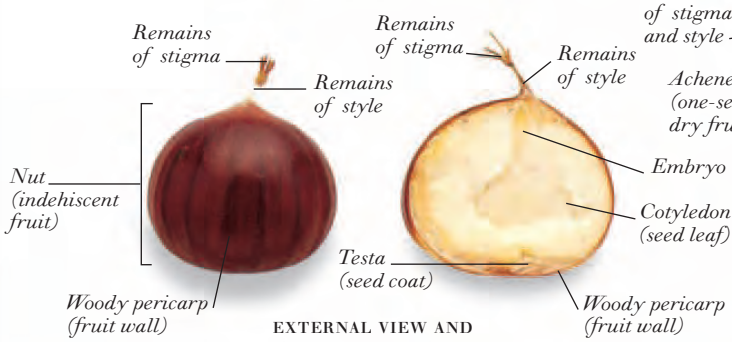
EXTERNAL VIEW OF FRUIT WITH SURROUNDING CUPULE

ACHENE
Strawberry
(*Fragaria* x *ananassa*)

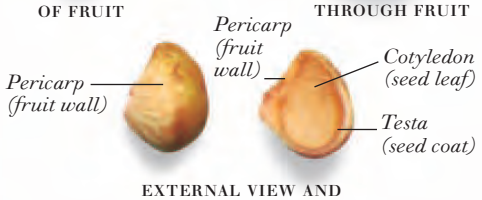


EXTERNAL VIEW OF FRUIT

LONGITUDINAL SECTION THROUGH FRUIT

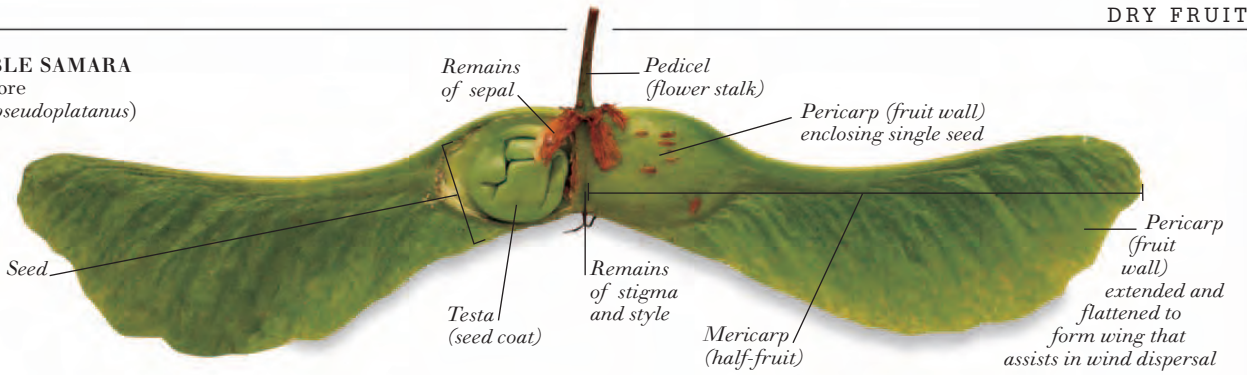


EXTERNAL VIEW AND SECTION THROUGH FRUIT

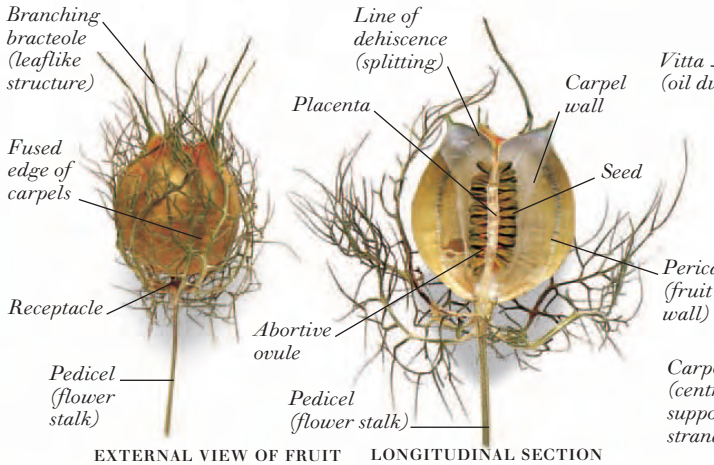


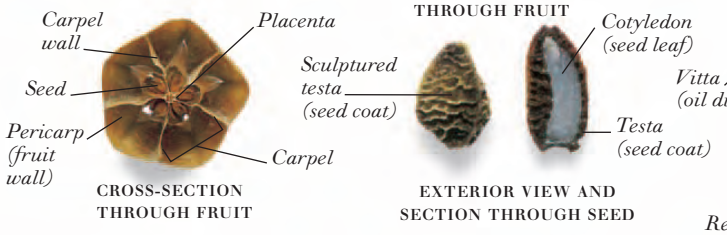
EXTERNAL VIEW AND SECTION THROUGH SEED

DOUBLE SAMARA
Sycamore
(*Acer pseudoplatanus*)

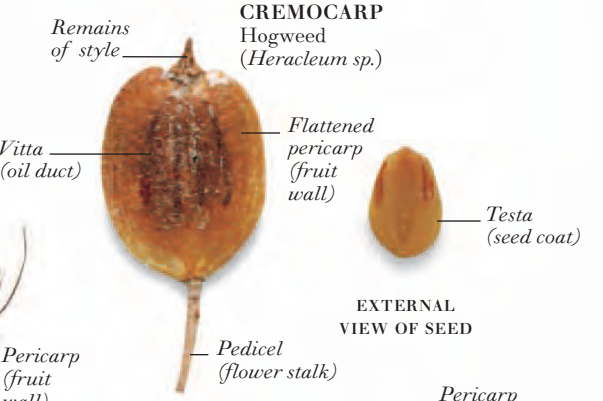


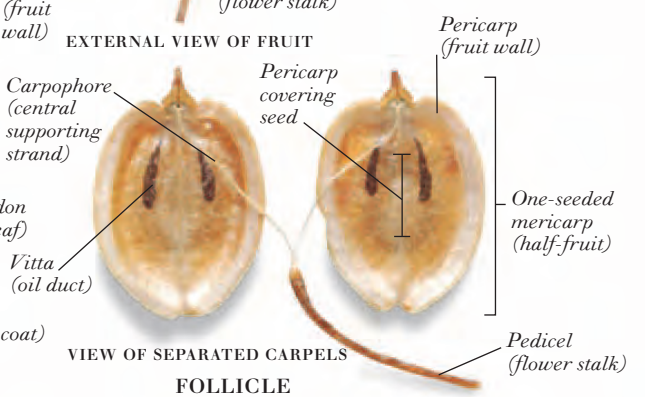
CAPSULE
Love-in-a-mist
(*Nigella damascena*)



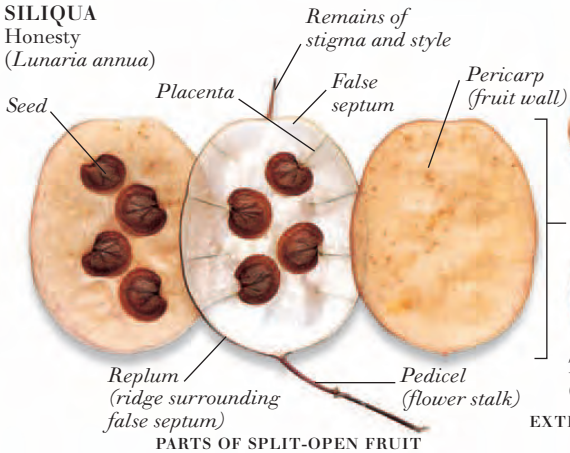


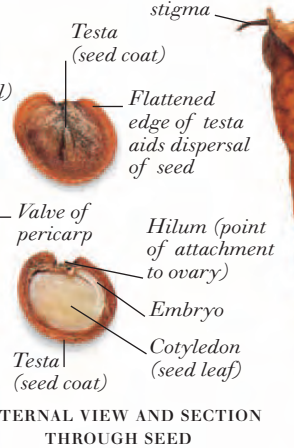
CREMOCARP
Hogweed
(*Heracleum sp.*)



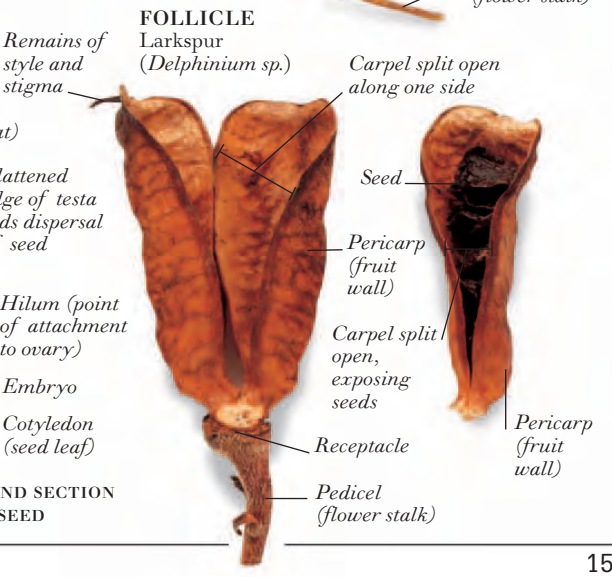


SILIQUA
Honesty
(*Lunaria annua*)



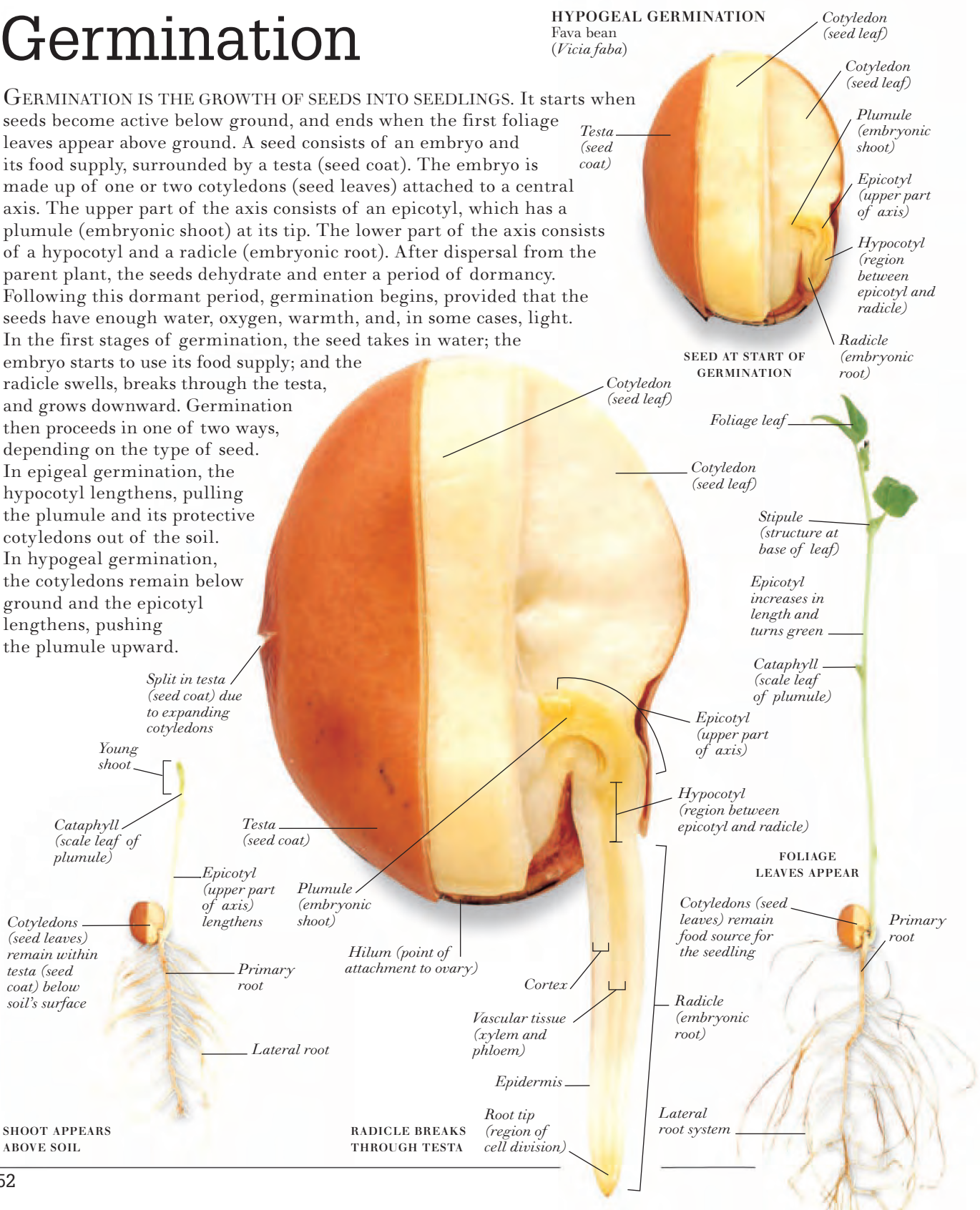


FOLLICLE
Larkspur
(*Delphinium sp.*)



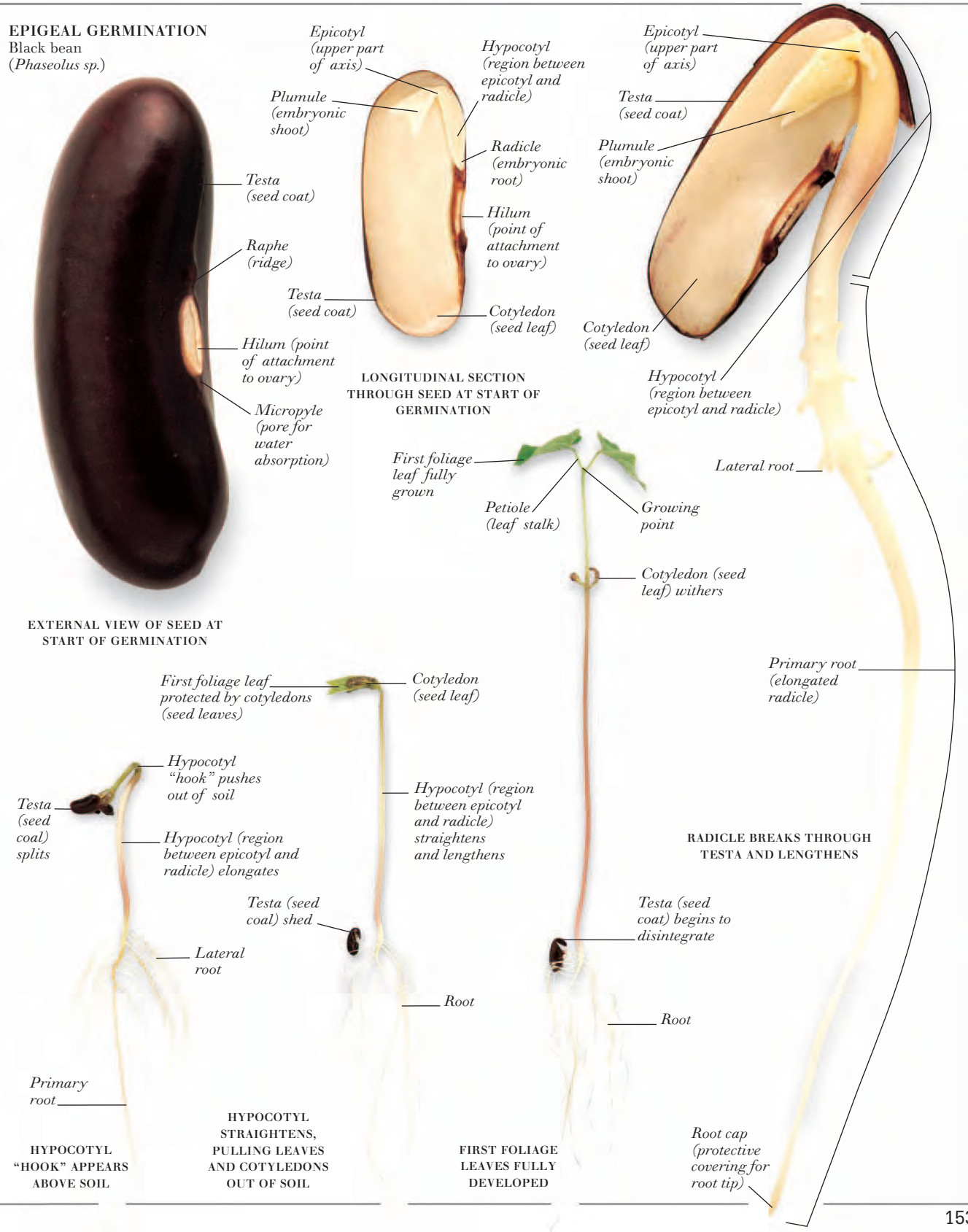
Germination

GERMINATION IS THE GROWTH OF SEEDS INTO SEEDLINGS. It starts when seeds become active below ground, and ends when the first foliage leaves appear above ground. A seed consists of an embryo and its food supply, surrounded by a testa (seed coat). The embryo is made up of one or two cotyledons (seed leaves) attached to a central axis. The upper part of the axis consists of an epicotyl, which has a plumule (embryonic shoot) at its tip. The lower part of the axis consists of a hypocotyl and a radicle (embryonic root). After dispersal from the parent plant, the seeds dehydrate and enter a period of dormancy. Following this dormant period, germination begins, provided that the seeds have enough water, oxygen, warmth, and, in some cases, light. In the first stages of germination, the seed takes in water; the embryo starts to use its food supply; and the radicle swells, breaks through the testa, and grows downward. Germination then proceeds in one of two ways, depending on the type of seed. In epigeal germination, the hypocotyl lengthens, pulling the plumule and its protective cotyledons out of the soil. In hypogeal germination, the cotyledons remain below ground and the epicotyl lengthens, pushing the plumule upward.



EPIGEAL GERMINATION

Black bean
(*Phaseolus sp.*)



EXTERNAL VIEW OF SEED AT START OF GERMINATION

LONGITUDINAL SECTION THROUGH SEED AT START OF GERMINATION

RADICLE BREAKS THROUGH TESTA AND LENGTHENS

HYPOCOTYL "HOOK" APPEARS ABOVE SOIL

HYPOCOTYL STRAIGHTENS, PULLING LEAVES AND COTYLEDONS OUT OF SOIL

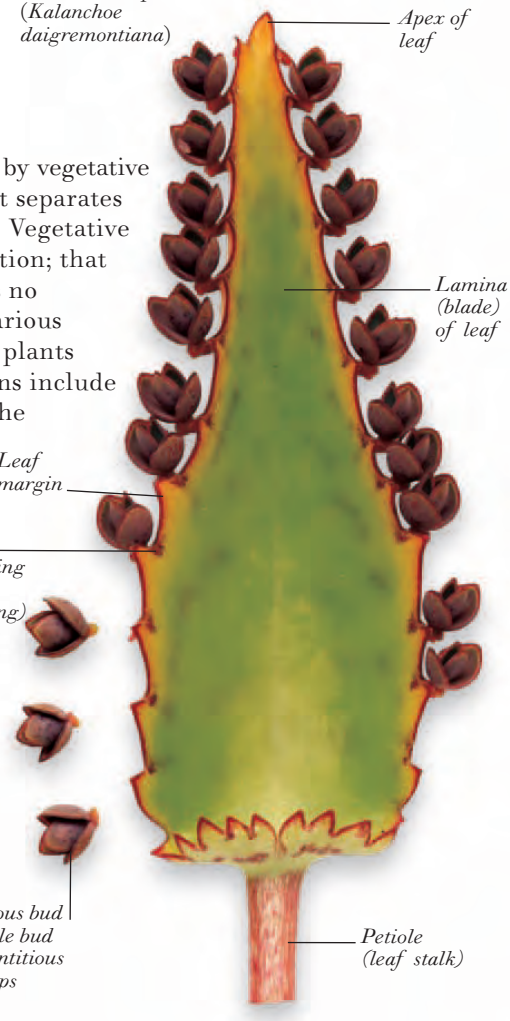
FIRST FOLIAGE LEAVES FULLY DEVELOPED

Vegetative reproduction

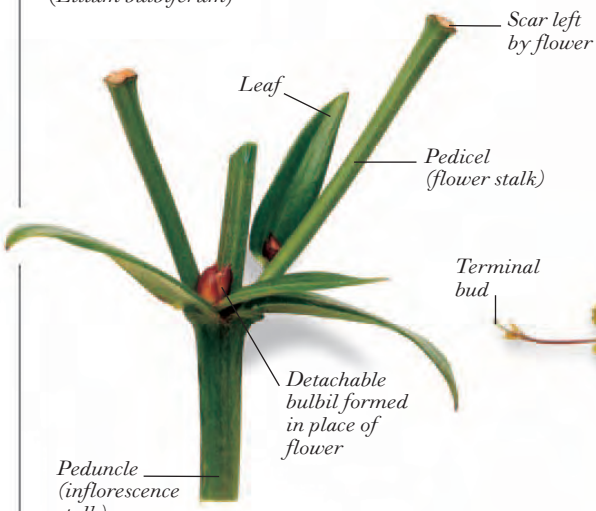
CORM
Gladiolus
(*Gladiolus sp.*)

MANY PLANTS CAN PROPAGATE THEMSELVES by vegetative reproduction. In this process, part of a plant separates off, takes root, and grows into a new plant. Vegetative reproduction is a type of asexual reproduction; that is, it involves only one parent, and there is no fusion of gametes (sex cells). Plants use various structures to reproduce vegetatively. Some plants use underground storage organs. Such organs include rhizomes (horizontal, underground stems), the branches of which produce new plants; bulbs (swollen leaf bases) and corms (swollen stems), which produce daughter bulbs or corms that separate off from the parent; and stem tubers (thickened underground stems) and root tubers (swollen adventitious roots), which also separate off from the parent. Other propagative structures include runners and stolons, creeping horizontal stems that take root and produce new plants; bulbils, small bulbs that develop on the stem or in the place of flowers, and then drop off and grow into new plants; and adventitious buds, miniature plants that form on leaf margins before dropping to the ground and growing into mature plants.

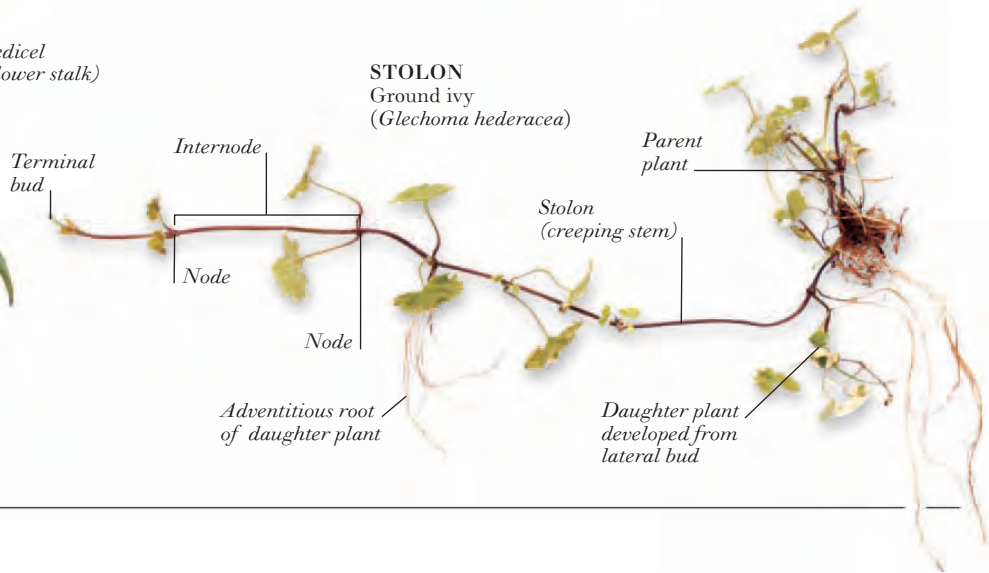
ADVENTITIOUS BUD
Mexican hat plant
(*Kalanchoe daigremontiana*)



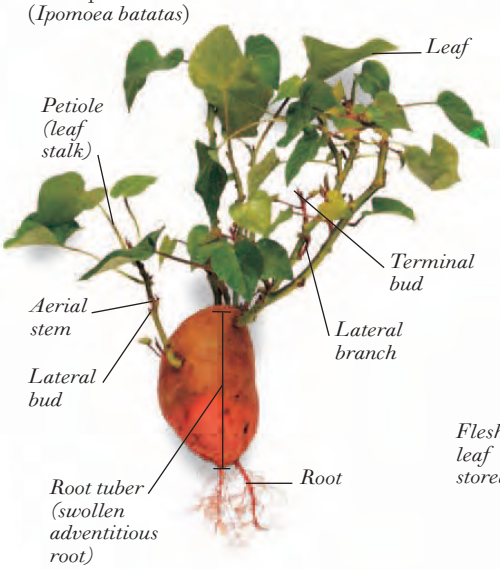
BULBIL IN PLACE OF FLOWER
Orange lily
(*Lilium bulbiferum*)



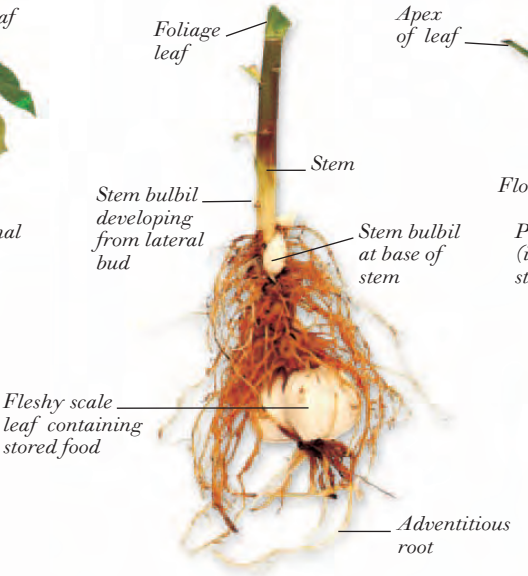
STOLON
Ground ivy
(*Glechoma hederacea*)



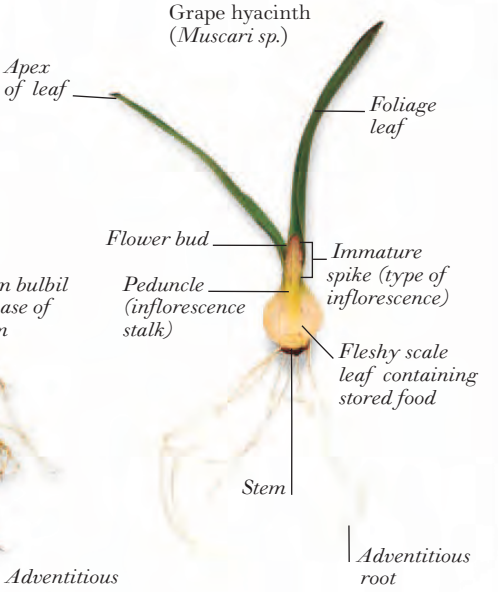
ROOT TUBER
Sweet potato
(*Ipomoea batatas*)



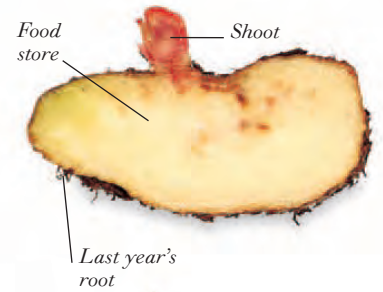
STEM BULBIL
Lily
(*Lilium sp.*)



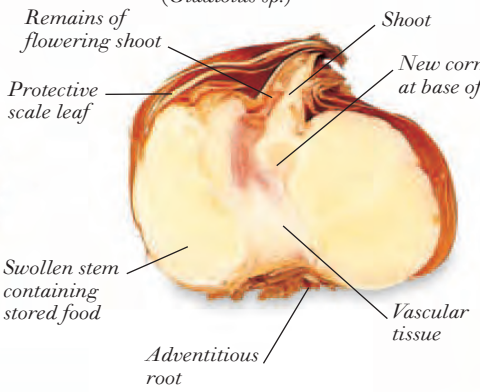
GROWING BULB
Grape hyacinth
(*Muscari sp.*)



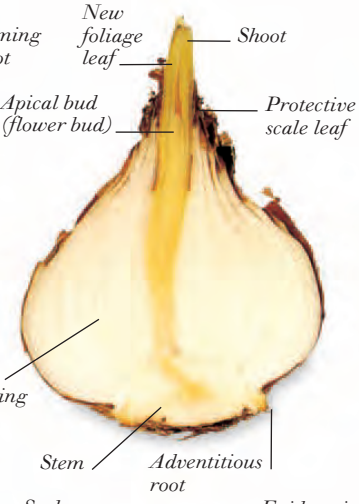
ROOT TUBER
Begonia
(*Begonia* x *tuberhybrida*)

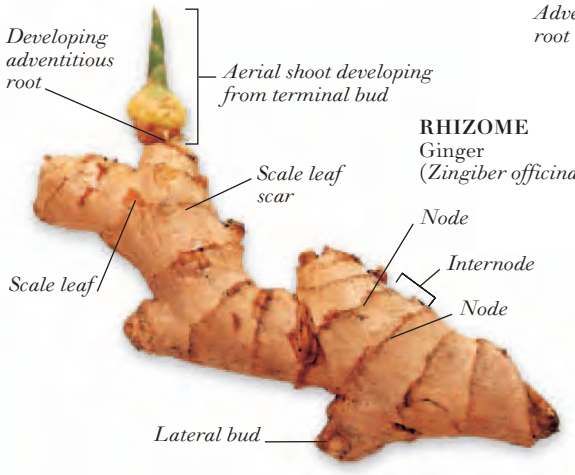


CORM
Gladiolus
(*Gladiolus sp.*)



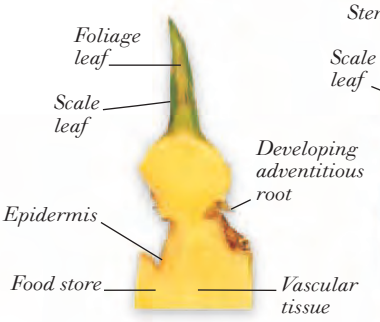
BULB WITH SHOOT
Amaryllis
(*Hippeastrum sp.*)



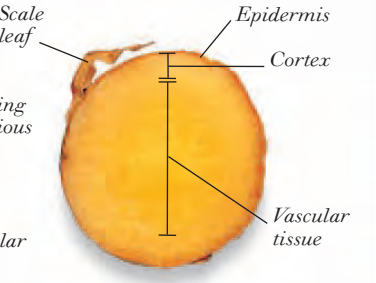


EXTERNAL VIEW

RHIZOME
Ginger
(*Zingiber officinale*)



LONGITUDINAL SECTION THROUGH AERIAL SHOOT



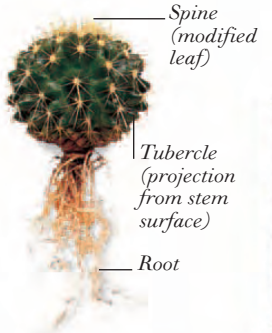
CROSS-SECTION THROUGH RHIZOME

Dryland plants

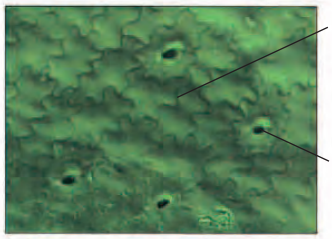
LEAF SUCCULENT
Lithops sp.

DRYLAND PLANTS (XEROPHYTES) are able to survive in unfavorable habitats. All are found in places where little water is available; some live in high temperatures that cause excessive loss of water from the leaves. Xerophytes show a number of adaptations to dry conditions; these include reduced leaf area, rolled leaves, sunken stomata, hairs, spines, and thick cuticles. One group, succulent plants, stores water in specially enlarged spongy tissues found in leaves, roots, or stems. Leaf succulents have enlarged, fleshy, water-storing leaves. Root succulents have a large, underground water-storage organ with short-lived stems and leaves above ground. Stem succulents are represented by the cacti (family Cactaceae). Cacti stems are fleshy, green, and photosynthetic; they are typically ribbed or covered by tubercles in rows, with leaves being reduced to spines or entirely absent.

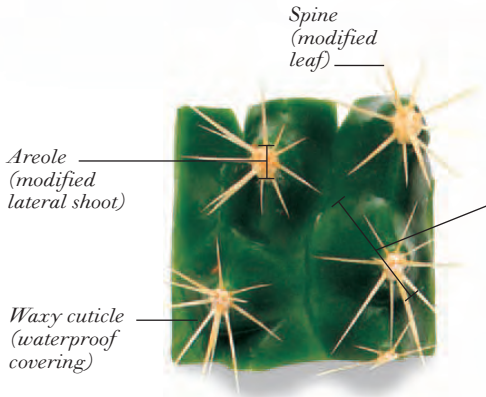
STEM SUCCULENT
Golden barrel cactus
(*Echinocactus grusonii*)



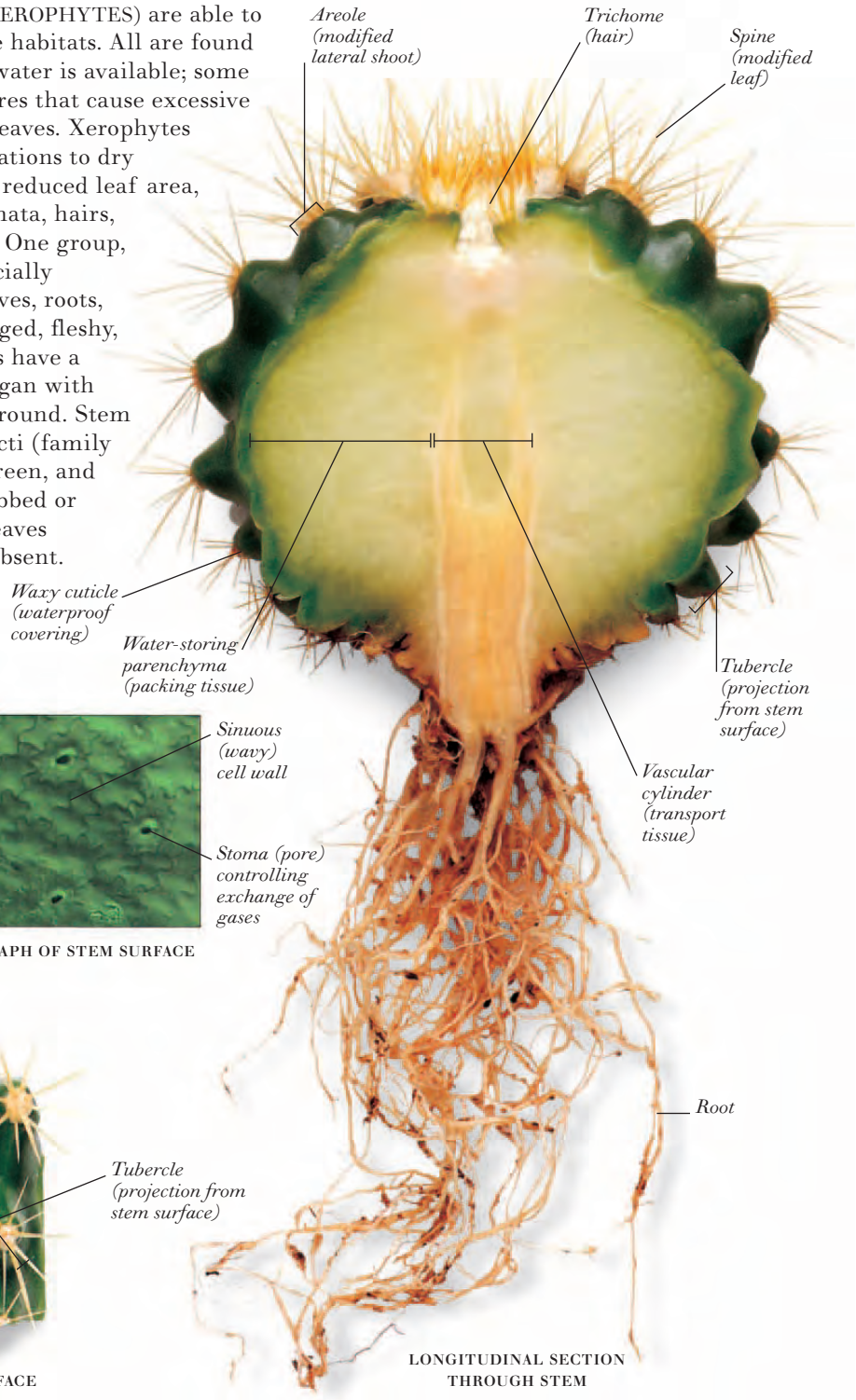
EXTERNAL VIEW



MICROGRAPH OF STEM SURFACE

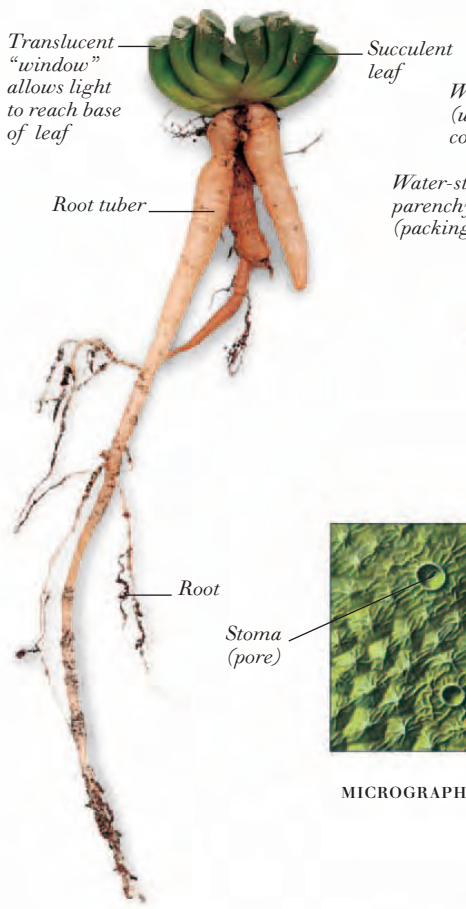


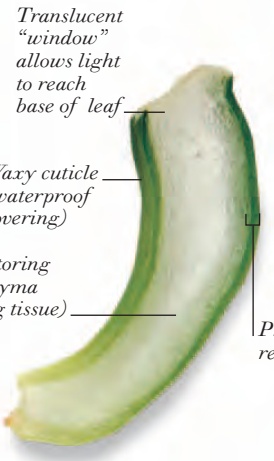
DETAIL OF STEM SURFACE



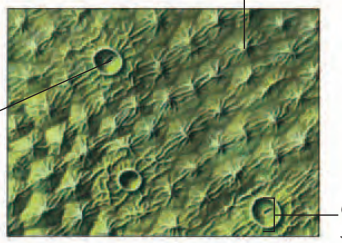
LONGITUDINAL SECTION THROUGH STEM

LEAF SUCCULENT
Haworthia truncata



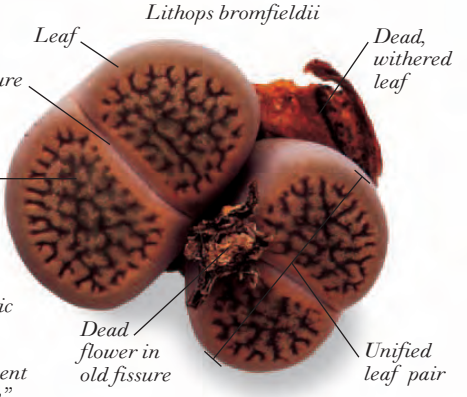


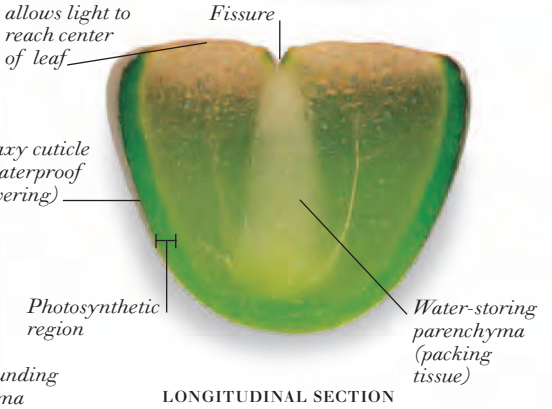
LONGITUDINAL SECTION THROUGH LEAF



MICROGRAPH OF LEAF SURFACE

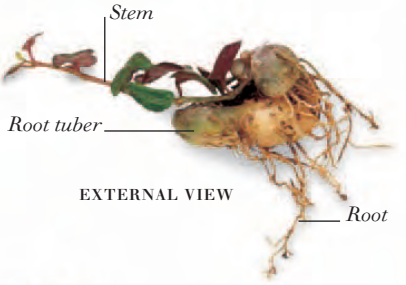
LEAF SUCCULENT
Lithops bromfieldii



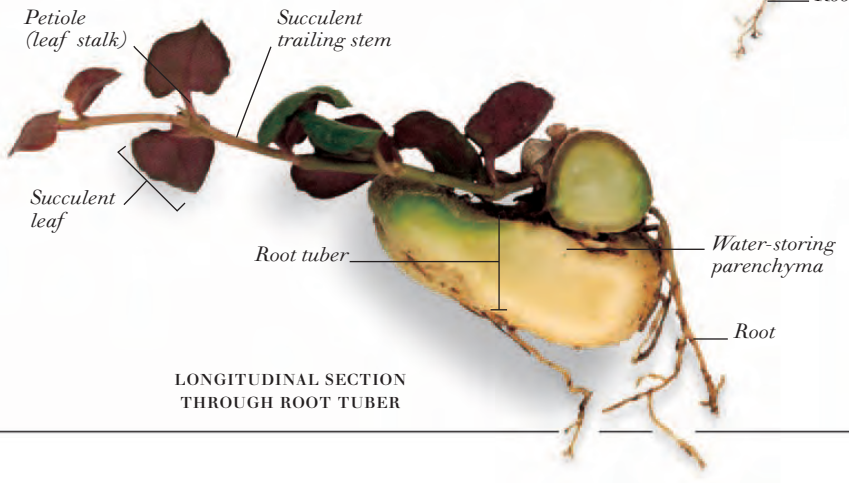


LONGITUDINAL SECTION THROUGH LEAF PAIR

STEM AND ROOT SUCCULENT
String of hearts
(*Ceropegia woodii*)

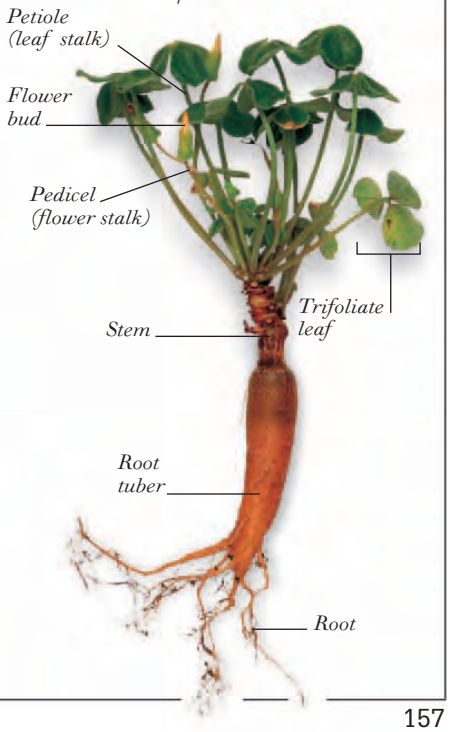


EXTERNAL VIEW



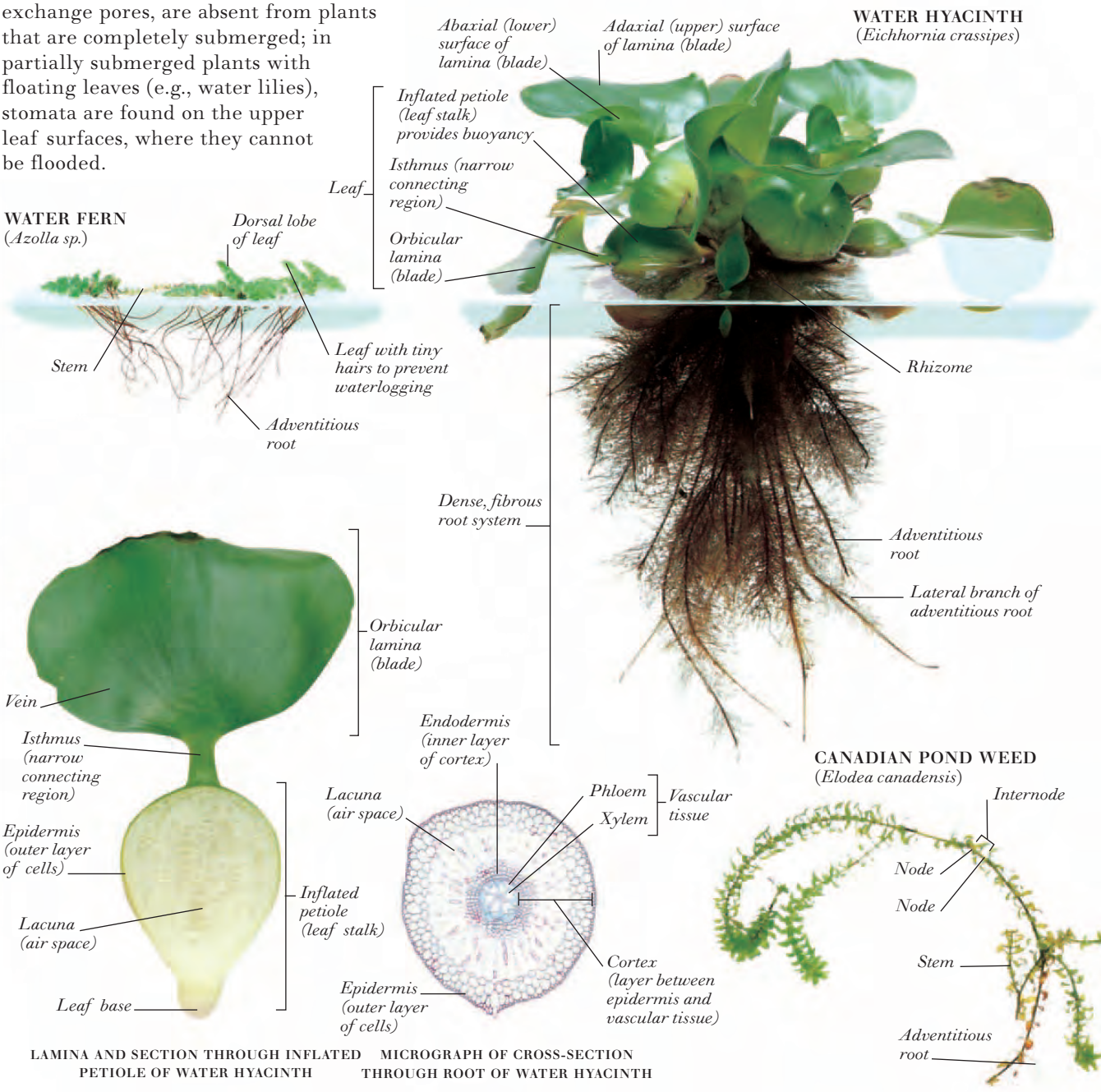
LONGITUDINAL SECTION THROUGH ROOT TUBER

ROOT SUCCULENT
Oxalis sp.



Wetland plants

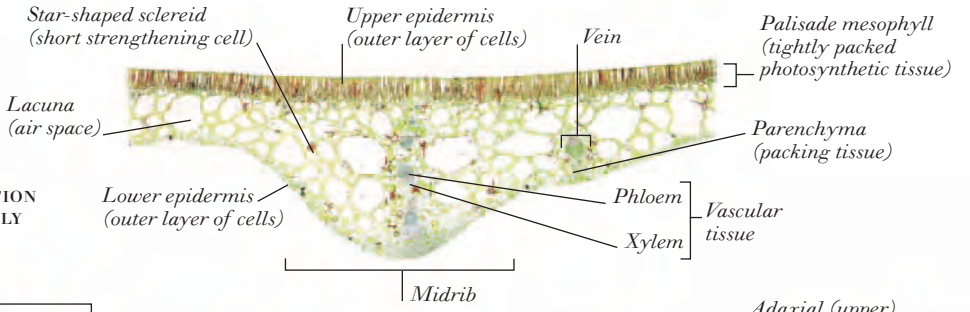
WETLAND PLANTS GROW SUBMERGED IN WATER, either partially (e.g., water hyacinth) or completely (e.g., pond weeds), and show various adaptations to this habitat. Typically, there are numerous air spaces inside the stems, leaves, and roots; these aid gas exchange and buoyancy. Submerged parts generally have no cuticle (waterproof covering), enabling the plants to absorb minerals and gases directly from the water; in addition, being supported by the water, they need little of the supportive tissue found in land plants. Stomata, the gas exchange pores, are absent from plants that are completely submerged; in partially submerged plants with floating leaves (e.g., water lilies), stomata are found on the upper leaf surfaces, where they cannot be flooded.



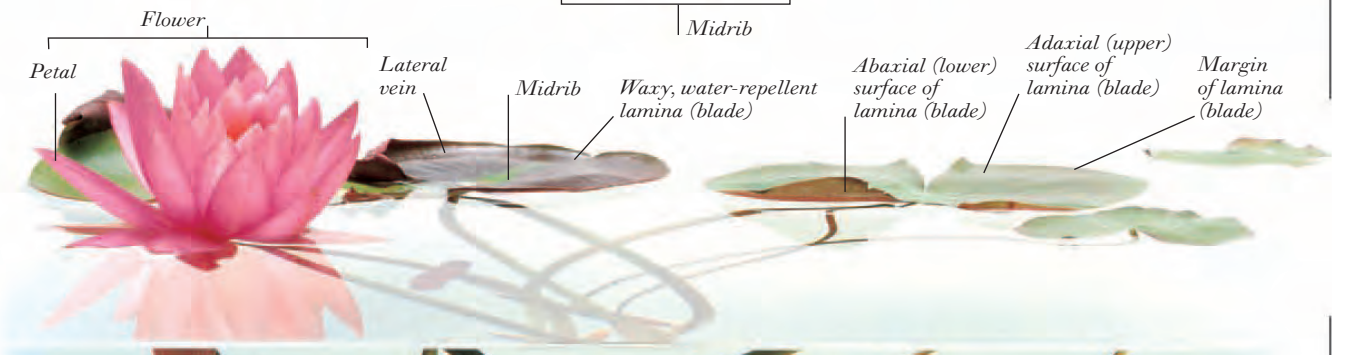
LAMINA AND SECTION THROUGH INFLATED PETIOLE OF WATER HYACINTH

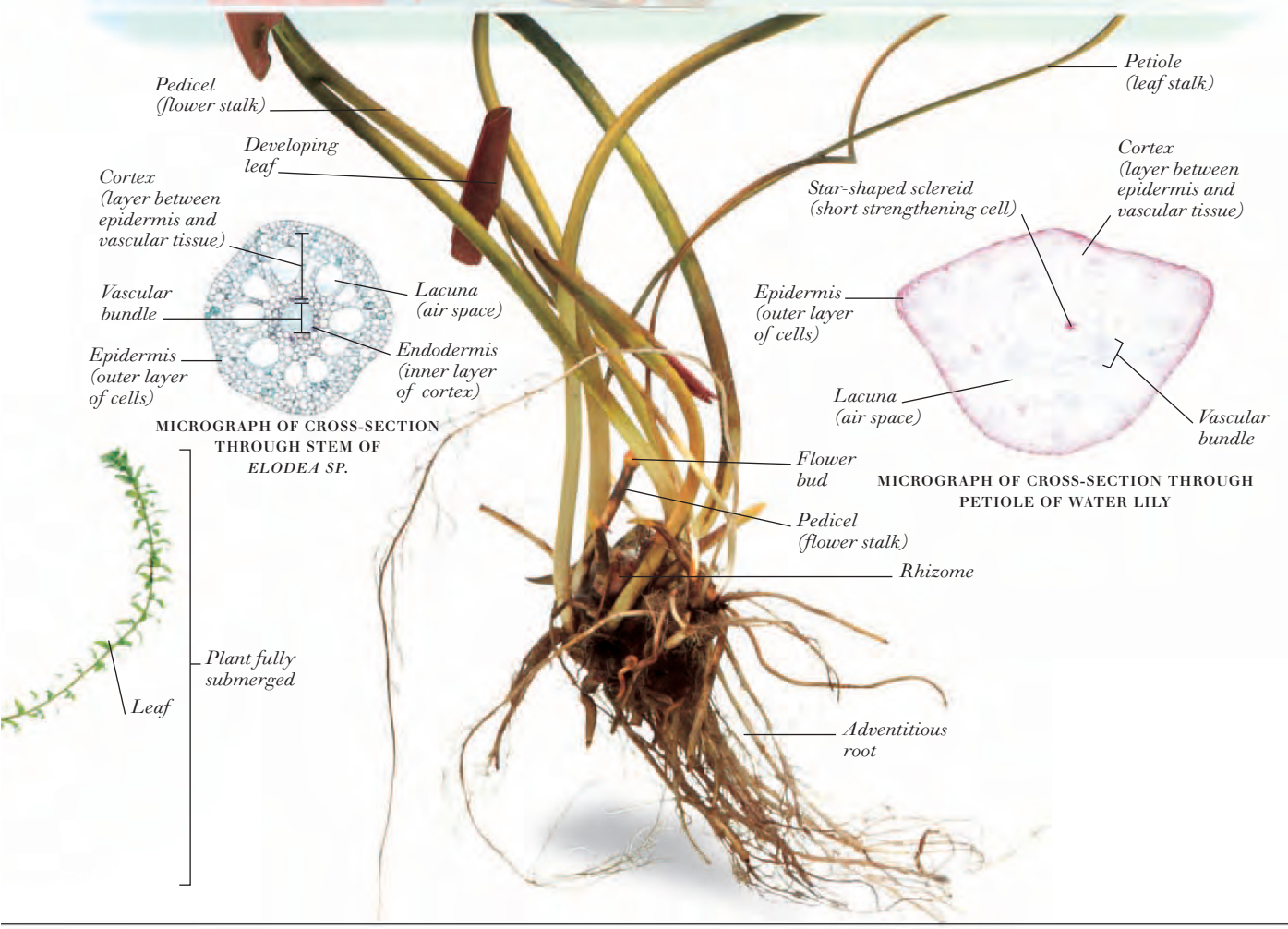
MICROGRAPH OF CROSS-SECTION THROUGH ROOT OF WATER HYACINTH

WATER LILY
(*Nymphaea sp.*)



MICROGRAPH OF CROSS-SECTION THROUGH LEAF OF WATER LILY



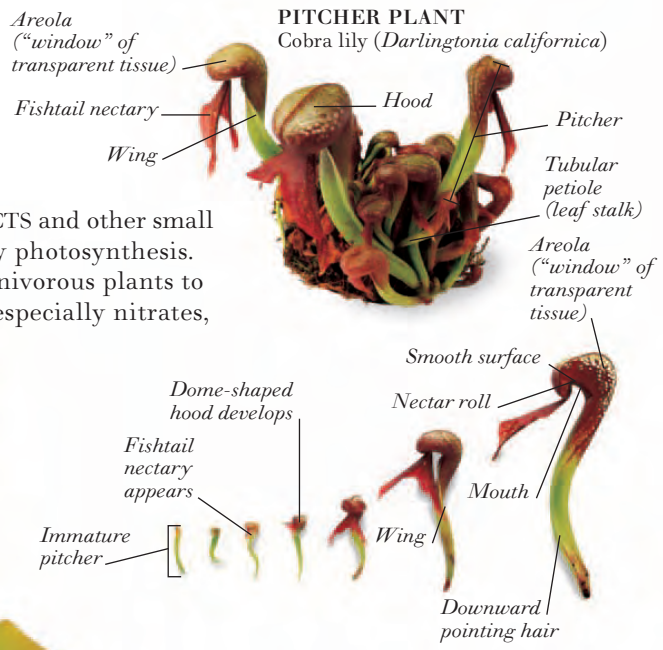


MICROGRAPH OF CROSS-SECTION THROUGH STEM OF *ELODEA SP.*

MICROGRAPH OF CROSS-SECTION THROUGH PETIOLE OF WATER LILY

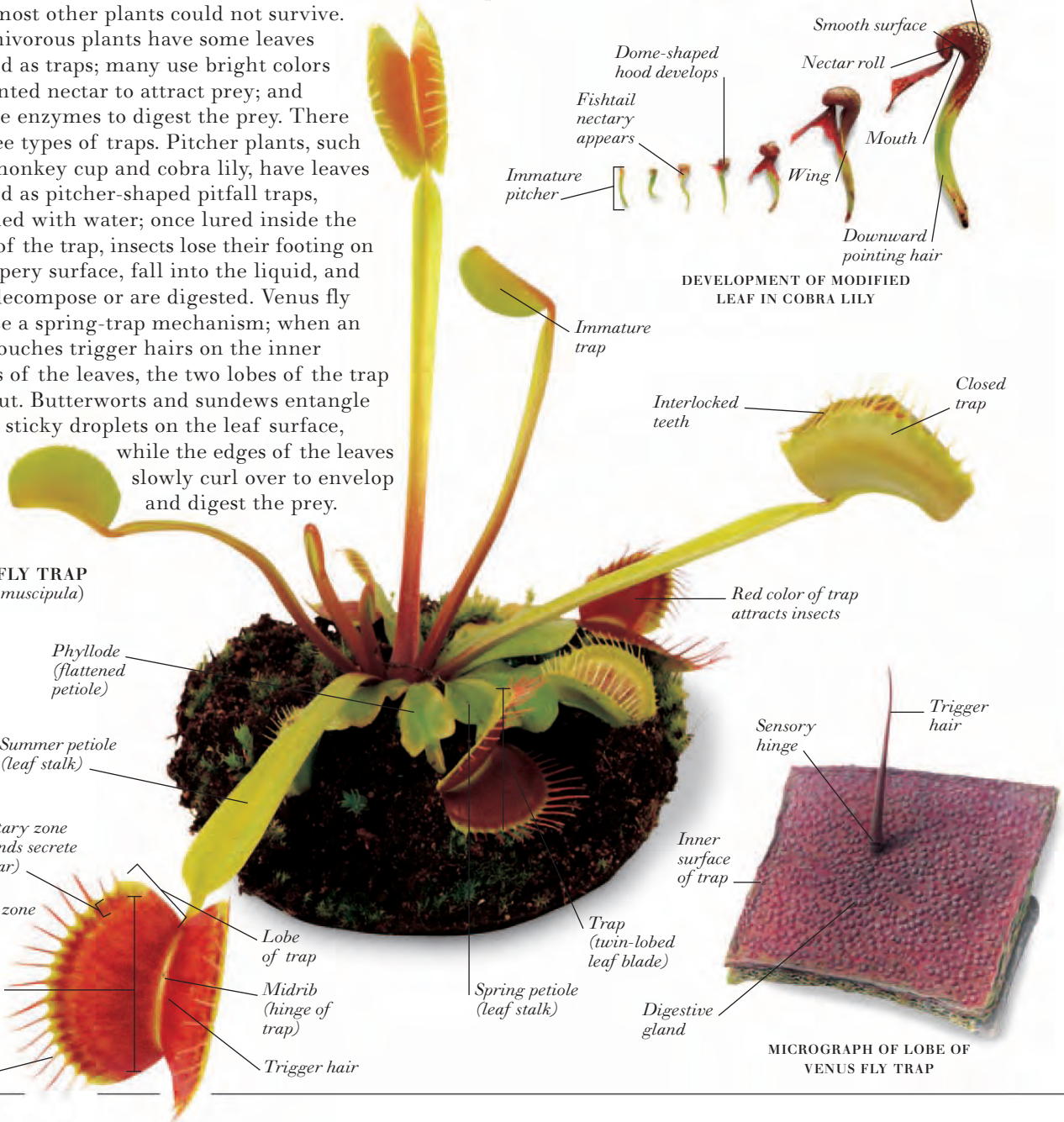
Carnivorous plants

CARNIVOROUS (INSECTIVOROUS) PLANTS FEED ON INSECTS and other small animals, in addition to producing food in their leaves by photosynthesis. The nutrients absorbed from trapped insects enable carnivorous plants to thrive in acid, boggy soils that lack essential minerals, especially nitrates, where most other plants could not survive. All carnivorous plants have some leaves modified as traps; many use bright colors and scented nectar to attract prey; and most use enzymes to digest the prey. There are three types of traps. Pitcher plants, such as the monkey cup and cobra lily, have leaves modified as pitcher-shaped pitfall traps, half-filled with water; once lured inside the mouth of the trap, insects lose their footing on the slippery surface, fall into the liquid, and either decompose or are digested. Venus fly traps use a spring-trap mechanism; when an insect touches trigger hairs on the inner surfaces of the leaves, the two lobes of the trap snap shut. Butterworts and sundews entangle prey by sticky droplets on the leaf surface, while the edges of the leaves slowly curl over to envelop and digest the prey.



PITCHER PLANT
Cobra lily (*Darlingtonia californica*)

DEVELOPMENT OF MODIFIED LEAF IN COBRA LILY



VENUS FLY TRAP
(*Dionaea muscipula*)

MICROGRAPH OF LOBE OF VENUS FLY TRAP

PITCHER PLANT
Monkey cup
(*Nepenthes mirabalis*)

Lamina (blade)
Tendril
Immature pitcher
Lid
Rim of pitcher
Mouth of pitcher
Pitcher

Inner surface of pitcher
Digestive gland
Outer surface of pitcher

MICROGRAPH OF WALL OF PITCHER

Lamina (blade)
Nectar-secreting gland
Midrib
Lid (attracts insects; stops rainwater from flooding pitcher)
Spur
Rim of pitcher (containing nectar glands)
Tendril
Waxy zone (no foothold for insects)
Digestive zone (normally containing digestive fluid)
Partly digested insects
Digestive gland

SECTION THROUGH PITCHER

Lid opens
Lid remains firmly closed as pitcher develops
Mouth of pitcher
Recently formed leaf
Tendril elongates
Frontal rib
Tendril at tip of recently formed leaf
Swelling forms at tip of tendril
Immature pitcher fills with air
Mature pitcher

DEVELOPMENT OF MODIFIED LEAF IN PITCHER PLANT

BUTTERWORT
(*Pinguicula caudata*)

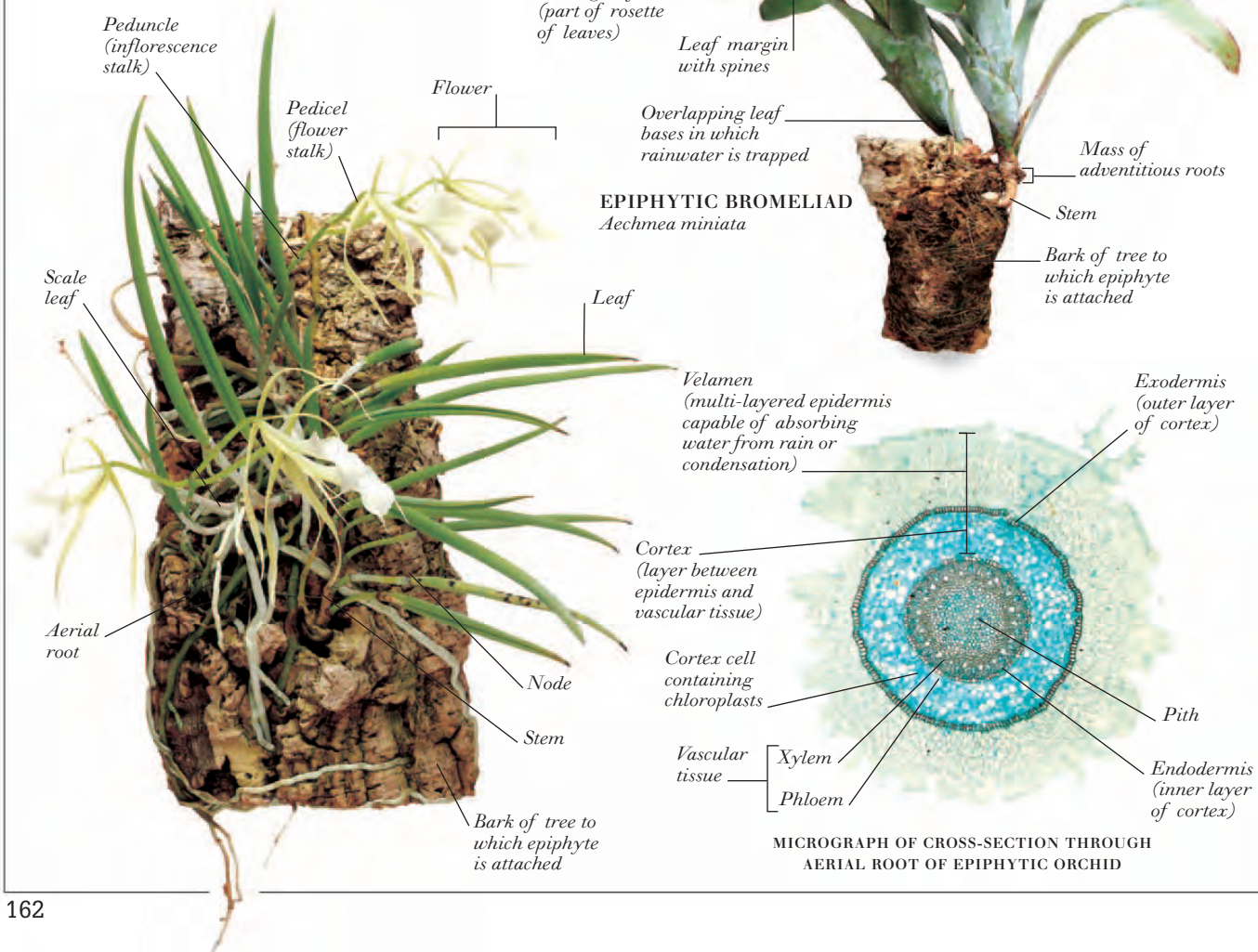
Stalked secretory gland (produces sticky, mucuslike substance)
Digestive gland (produces enzymes)
Adaxial (upper) surface of leaf
Abaxial (lower) surface of leaf

MICROGRAPH OF BUTTERWORT LEAF

Flattened lamina (blade)
Insect trapped on sticky surface of lamina (blade)
Margin of lamina (blade) rolled inwards
Immature leaf

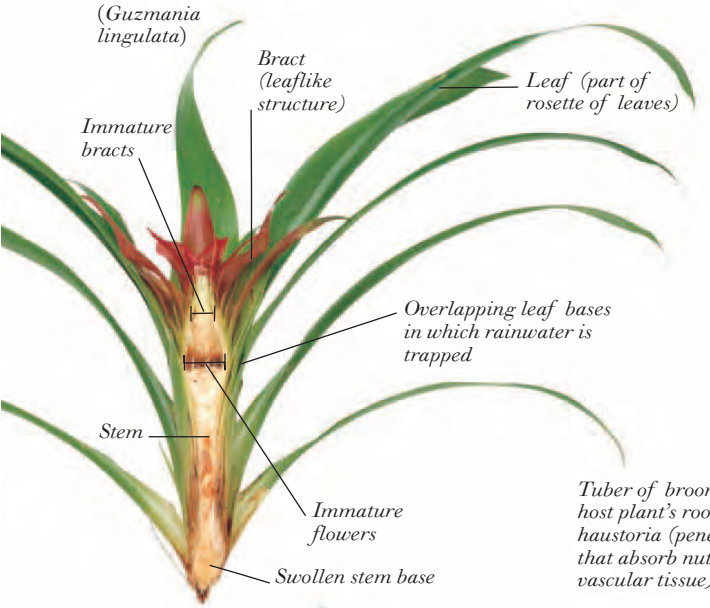
Epiphytic and parasitic plants

EPIPHYTIC AND PARASITIC PLANTS GROW ON OTHER LIVING PLANTS. Typically, epiphytic plants are not rooted in the soil; instead, they live above ground level on the stems and branches of other plants. Epiphytes obtain water from trapped rainwater and from moisture in the air, and minerals from organic matter that has accumulated on the surface of the plant on which they are growing. Like other green plants, epiphytes produce their food by photosynthesis. Epiphytes include tropical orchids and bromeliads (air plants), and some mosses that live in temperate regions. Parasitic plants obtain all their nutrient requirements from the host plants on which they grow. The parasites produce haustoria, rootlike organs that penetrate the stem or roots of the host and grow inward to merge with the host's vascular tissue, from which the parasite extracts water, minerals, and manufactured nutrients. As they have no need to produce their own food, parasitic plants lack chlorophyll, the green photosynthetic pigment, and they have no foliage leaves. Partial parasitic plants (e.g., mistletoe) obtain water and minerals from the host plant but have green leaves and stems and are therefore able to produce their own food by photosynthesis.



LONGITUDINAL SECTION THROUGH EPIPHYTIC BROMELIAD

Scarlet star
(*Guzmania lingulata*)

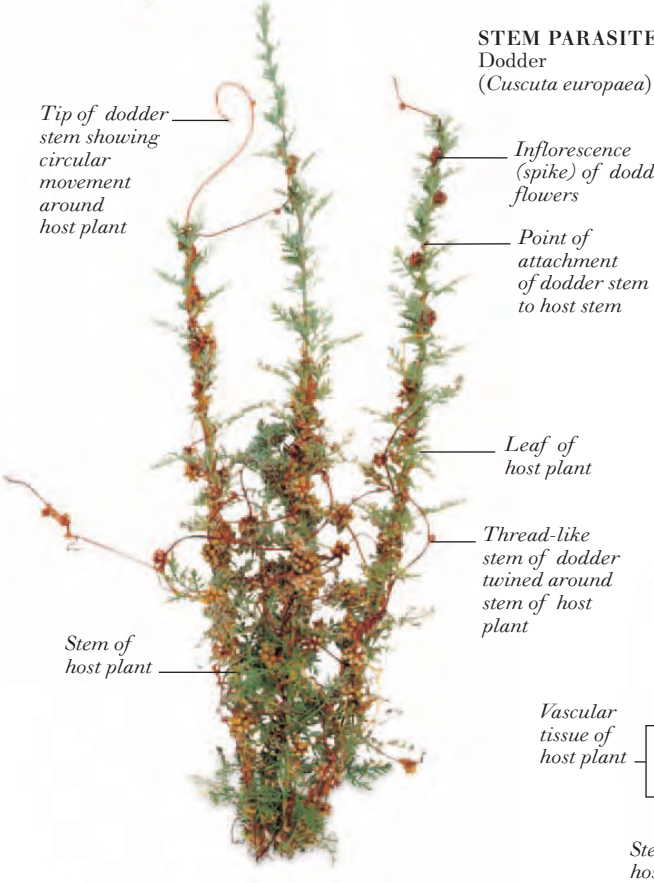


ROOT PARASITE

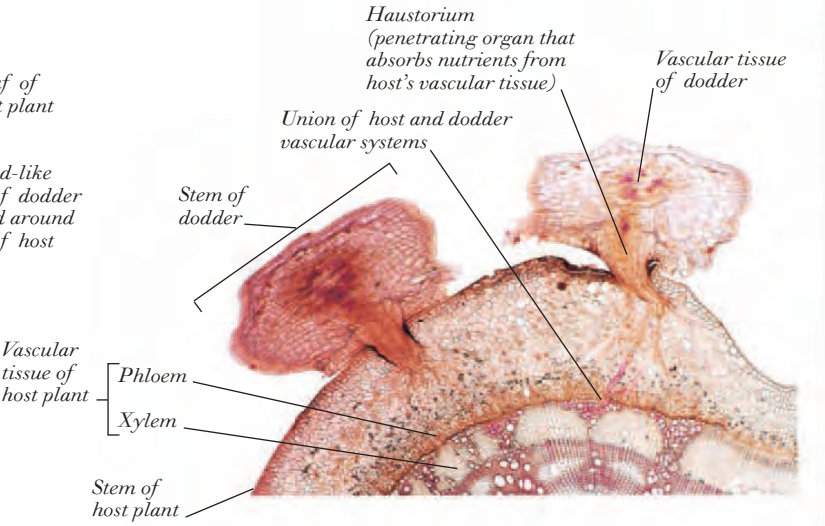
Broomrape
(*Orobanche sp.*)

STEM PARASITE

Dodder
(*Cuscuta europaea*)



EXTERNAL VIEW OF PLANT PARASITIZED BY DODDER



MICROGRAPH OF CROSS-SECTION THROUGH STEM OF PLANT PARASITIZED BY DODDER

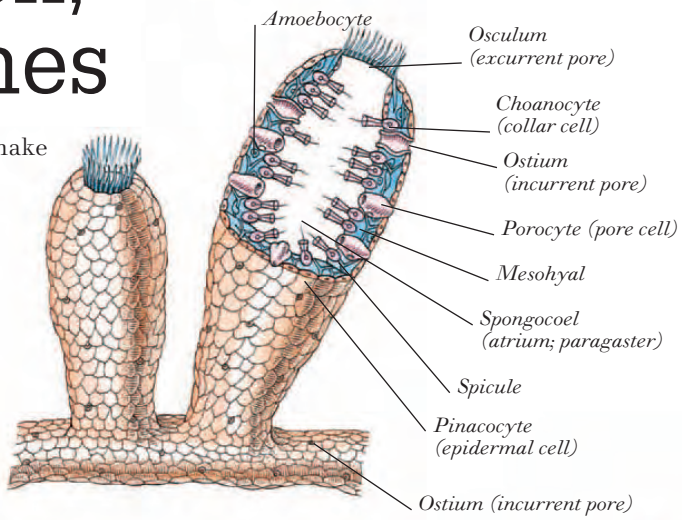
Animals

Sponges, Jellyfish, and Sea Anemones 166
Insects 168
Arachnids 170
Crustaceans 172
Starfish and Sea Urchins 174
Mollusks 176
Sharks and Jawless Fish 178
Bony Fish 180
Amphibians 182
Lizards and Snakes 184
Crocodilians and Turtles 186
Birds 1 188
Birds 2 190
Eggs 192
Carnivores 194
Rabbits and Rodents 196
Ungulates 198
Elephants 200
Primates 202
Dophins, Whales, and Seals 204
Marsupials and Monotremes 206

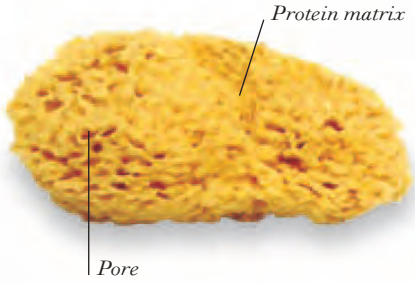
Sponges, jellyfish, and sea anemones

SPONGES ARE MAINLY MARINE animals that make up the phylum Porifera. They are among the simplest of all animals, having no tissues or organs. Their bodies consist of two layers of cells separated by a jellylike layer (mesohyal) that is strengthened by mineral spicules or protein fibers. The body is perforated by a system of pores and water channels called the aquiferous system. Special cells (choanocytes) with whiplike structures (flagella) draw water through the aquiferous system, thereby bringing tiny food particles to the sponge's cells. Jellyfish (class Scyphozoa), sea anemones (class Anthozoa), and corals (also class Anthozoa) belong to the phylum Cnidaria, also known as Coelenterata. More complex than sponges, coelenterates have simple tissues, such as nervous tissue; a radially symmetrical body; and a mouth surrounded by tentacles with unique stinging cells (cnidocytes).

INTERNAL ANATOMY OF A SPONGE

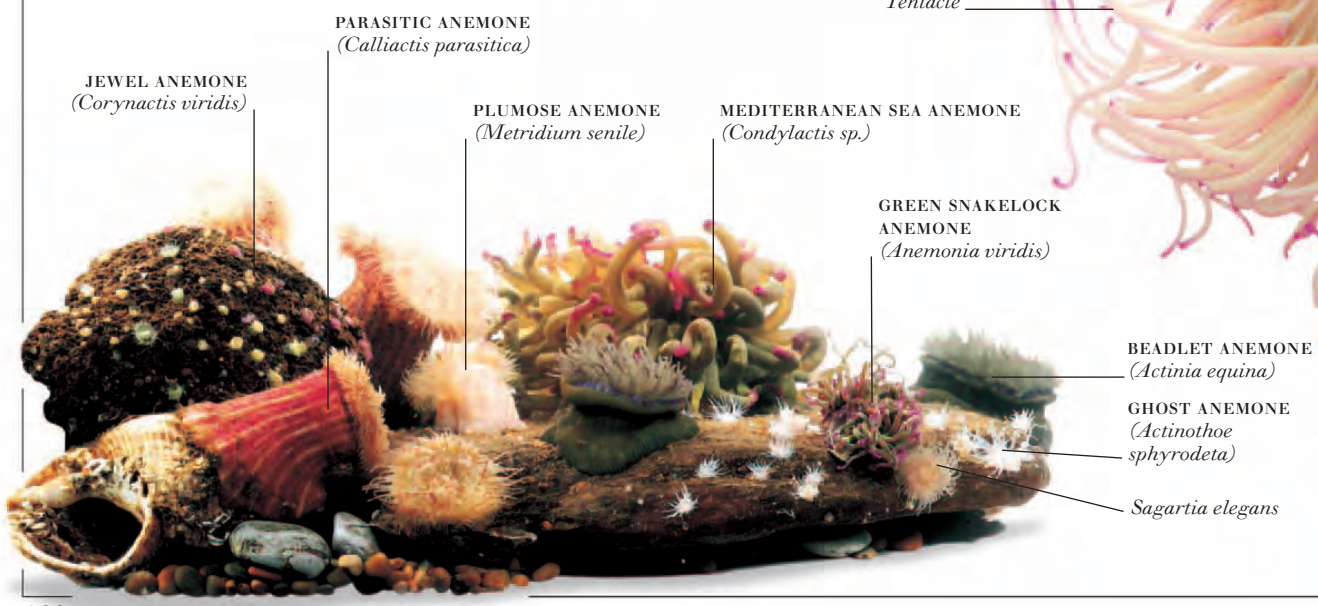


SKELETON OF A SPONGE



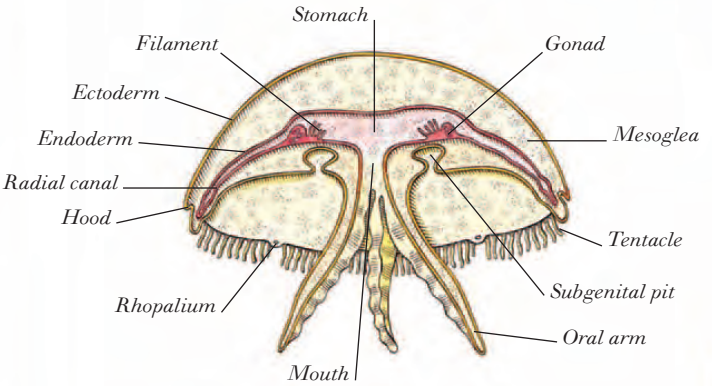
EXTERNAL FEATURES OF A SEA ANEMONE

EXAMPLES OF SEA ANEMONES



EXTERNAL APPEARANCE OF A JELLYFISH

INTERNAL ANATOMY OF A JELLYFISH



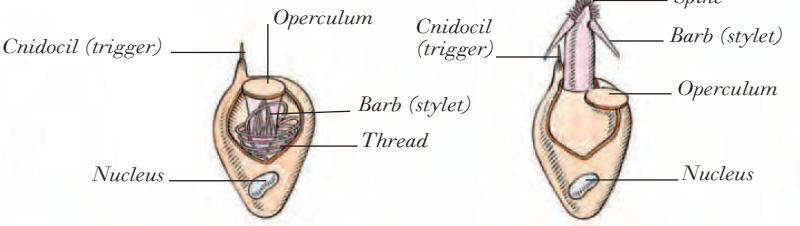
EXAMPLES OF CORALS

HONEYCOMB CORAL
(Goniastrea aspera)

MUSHROOM CORAL
(Fungia fungites)

STAR CORAL
(Balanophyllia regia)

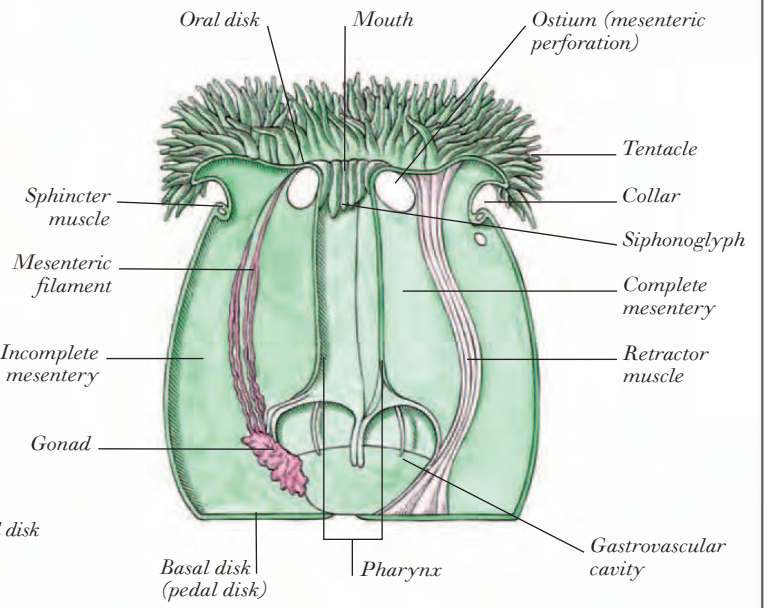
STRUCTURE OF A CNIDOCYTE



BEFORE DISCHARGE

AFTER DISCHARGE

INTERNAL ANATOMY OF A SEA ANEMONE

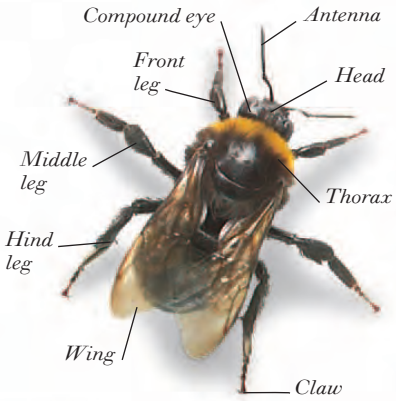


Insects

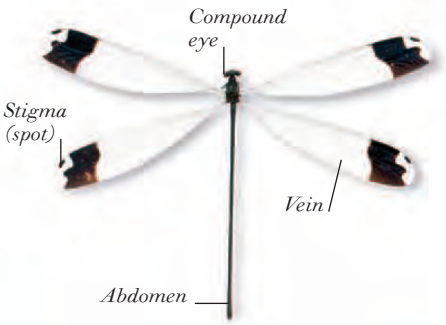
PUPA (CHRYSALIS)

THE WORD INSECT REFERS to small invertebrate creatures, especially those with bodies divided into sections. Insects, including beetles, ants, bees, butterflies, and moths, belong to various orders in the class Insecta, which is a division of the phylum Arthropoda. Features common to all insects are an exoskeleton (external skeleton); three pairs of jointed legs; three body sections (head, thorax, and abdomen); and one pair of sensory antennae. Beetles (order Coleoptera) are the biggest group of insect, with about 300,000 species (about 30 percent of all known insects). They have a pair of hard elytra (wing cases), which are modified front wings. The principal function of the elytra is to protect the hind wings, which are used for flying. Ants, together with bees and wasps, form the order Hymenoptera, which contains about 200,000 species. This group is characterized by a marked narrowing between the thorax and abdomen. Butterflies and moths form the order Lepidoptera, which has about 150,000 species. They have wings covered with tiny scales, hence the name of their order (Lepidoptera means "scale wings"). The separation of lepidopterans into butterflies and moths is largely artificial, since there are no features that categorically distinguish one group from the other. In general, however, most butterflies fly by day, whereas most moths are night-flyers. Some insects, including butterflies and moths, undergo complete metamorphosis (transformation) during their life-cycle. A butterfly metamorphoses from an egg to a larva (caterpillar), then to a pupa (chrysalis), and finally to an imago (adult).

EXAMPLES OF INSECTS

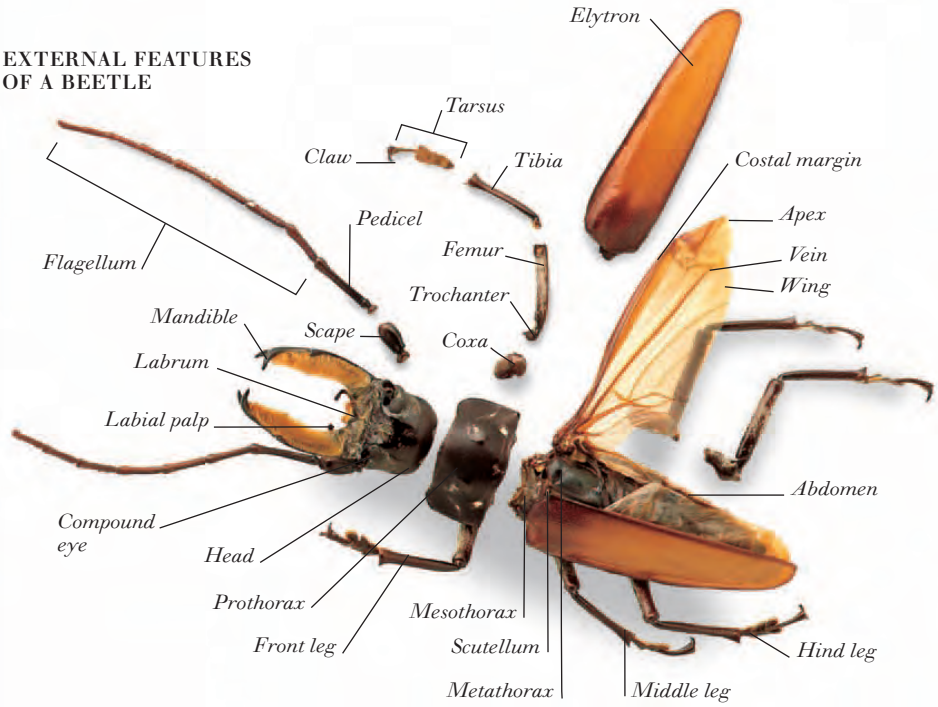


BUMBLEBEE



DAMSELFLY

EXTERNAL FEATURES OF A BEETLE

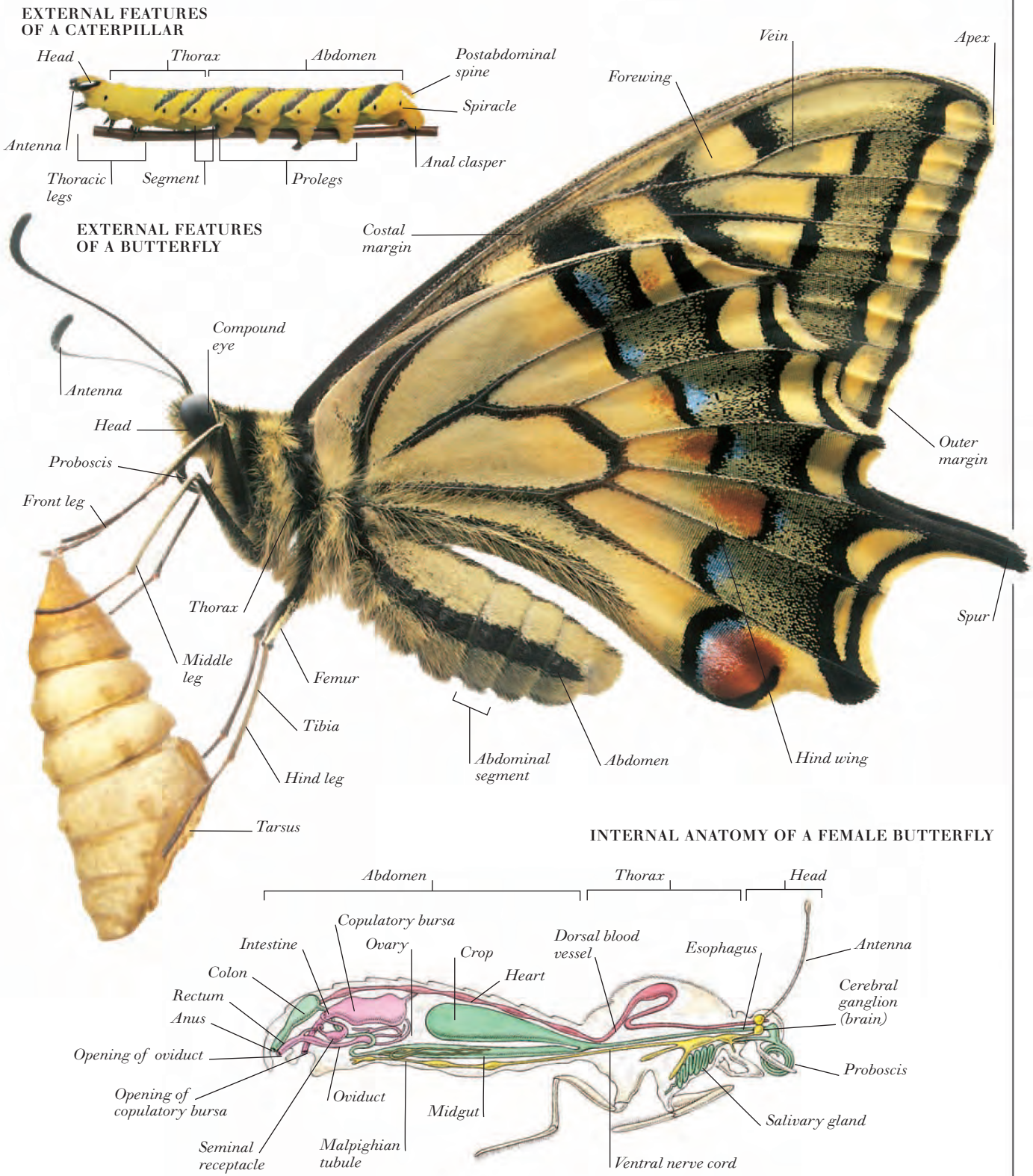


CRICKET

ANT

FLY

EARWIG

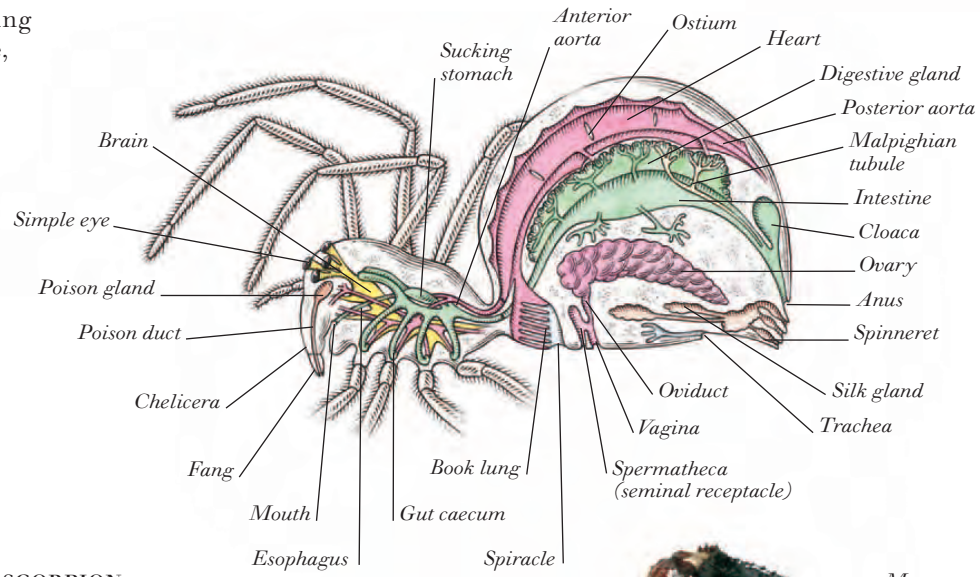

EXTERNAL FEATURES OF A CATERPILLAR
Head
Thorax
Abdomen
Postabdominal spine
Spiracle
Antenna
Anal clasper
Thoracic legs
Segment
Prolegs
EXTERNAL FEATURES OF A BUTTERFLY
Vein
Apex
Forewing
Costal margin
Compound eye
Antenna
Head
Proboscis
Front leg
Outer margin
Thorax
Spur
Middle leg
Femur
Tibia
Hind leg
Abdominal segment
Abdomen
Hind wing
Tarsus
INTERNAL ANATOMY OF A FEMALE BUTTERFLY
Abdomen
Thorax
Head
Copulatory bursa
Intestine
Ovary
Crop
Dorsal blood vessel
Esophagus
Antenna
Colon
Heart
Cerebral ganglion (brain)
Rectum
Anus
Opening of oviduct
Proboscis
Opening of copulatory bursa
Oviduct
Midgut
Salivary gland
Seminal receptacle
Malpighian tubule
Ventral nerve cord

Arachnids

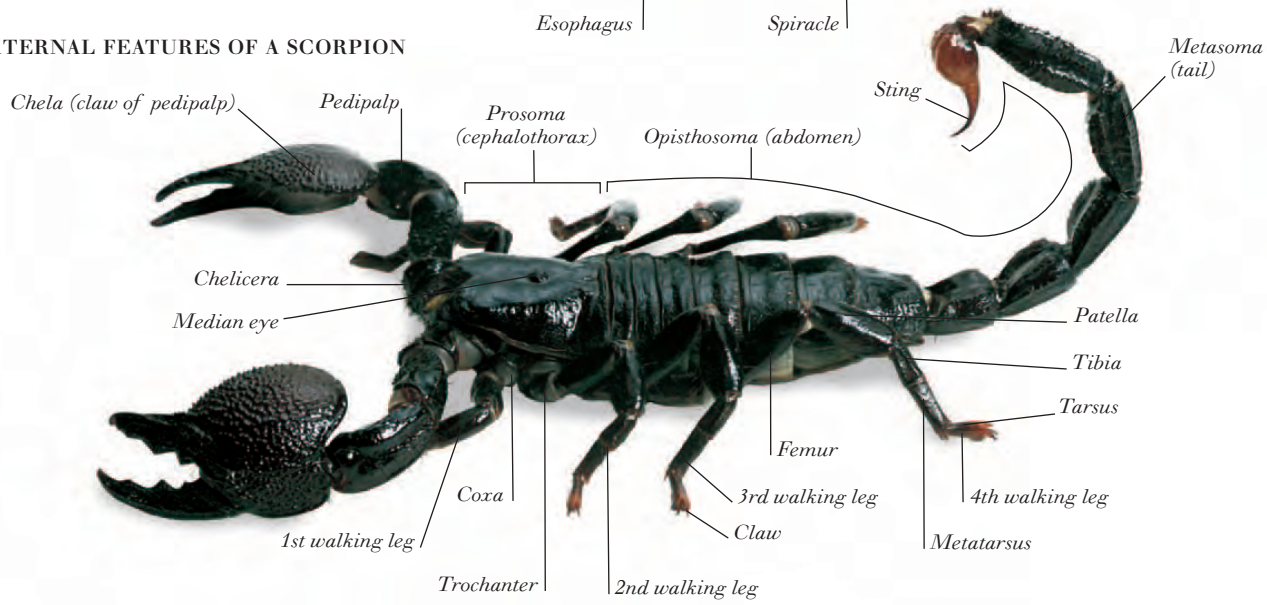
THE CLASS ARACHNIDA INCLUDES SPIDERS (order Araneae) and scorpions (order Scorpiones). The class is part of the phylum Arthropoda, which also includes insects and crustaceans. Spiders and scorpions are characterized by having four pairs of walking legs; a pair of pincerlike mouthparts called chelicerae; another pair of frontal appendages called pedipalps, which are sensory in spiders but used for grasping in scorpions; and a body divided into two sections (a combined head and thorax called a cephalothorax or prosoma, and an abdomen or opisthosoma). Unlike other arthropods, spiders and scorpions lack antennae. Spiders and scorpions are carnivorous. Spiders poison prey by biting with the fanged chelicerae, scorpions by stinging with the end of the metasoma (tail).

MEXICAN TRUE RED-LEGGED TARANTULA
(Euathlus emilia)

INTERNAL ANATOMY OF A FEMALE SPIDER



EXTERNAL FEATURES OF A SCORPION



EXAMPLES OF SPIDERS

RAFT SPIDER
(Dolomedes fimbriatus)

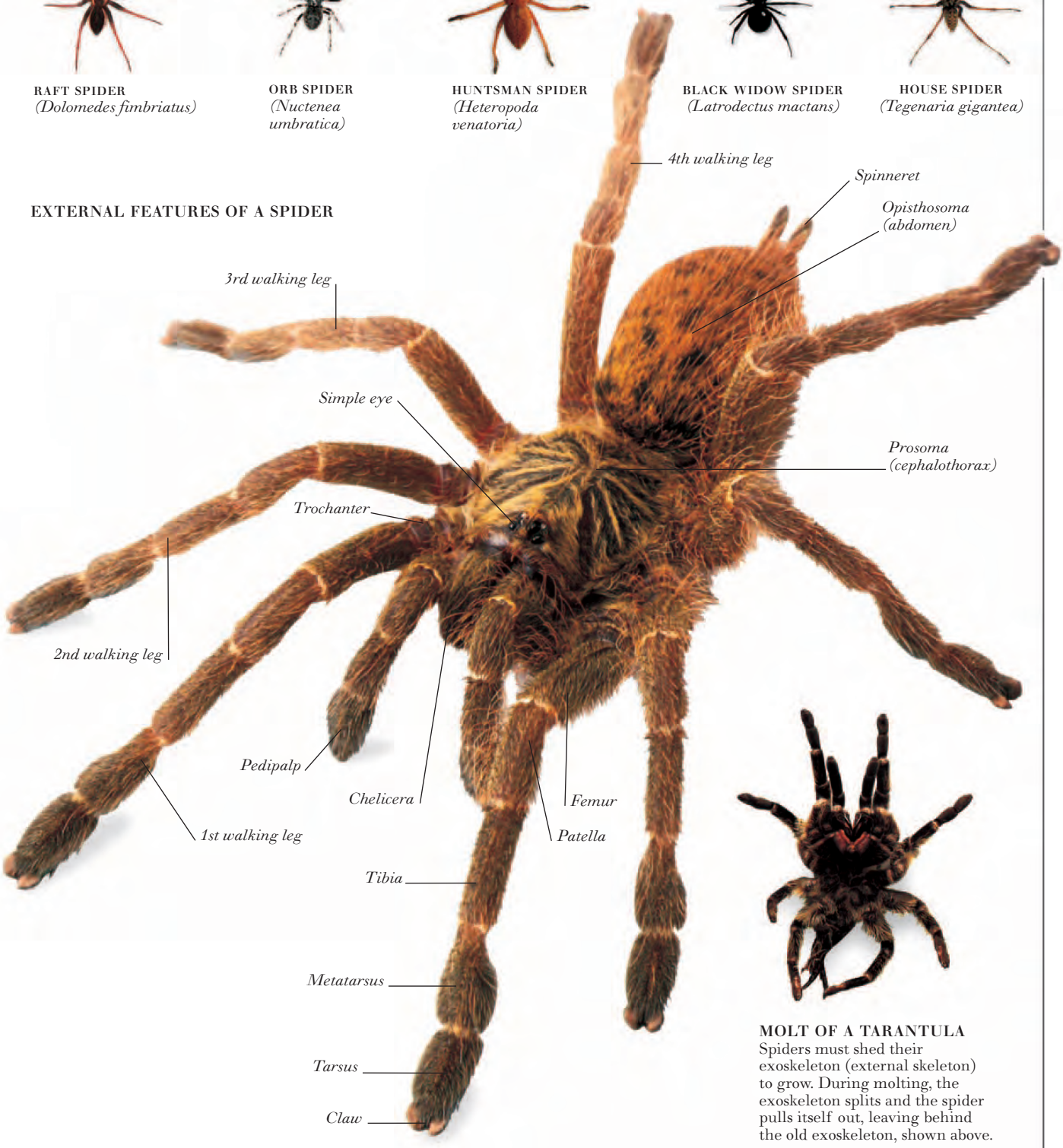
ORB SPIDER
(Nuctenea umbratica)

HUNTSMAN SPIDER
(Heteropoda venatoria)

BLACK WIDOW SPIDER
(Latrodectus mactans)

HOUSE SPIDER
(Tegenaria gigantea)

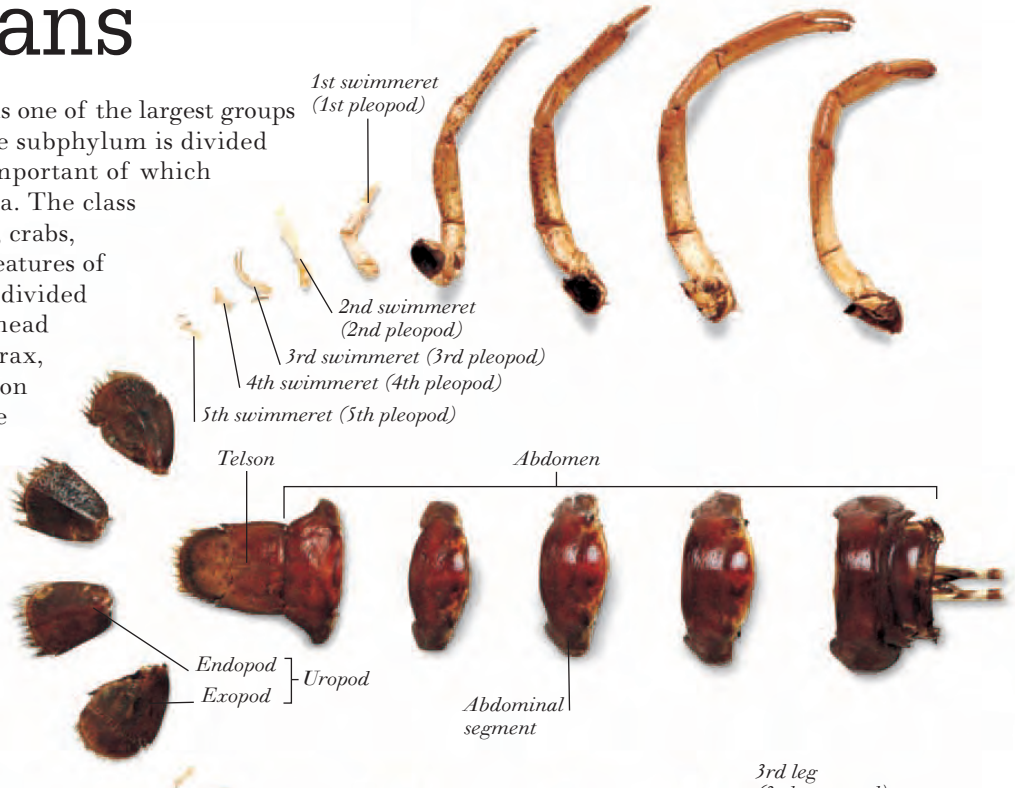
EXTERNAL FEATURES OF A SPIDER



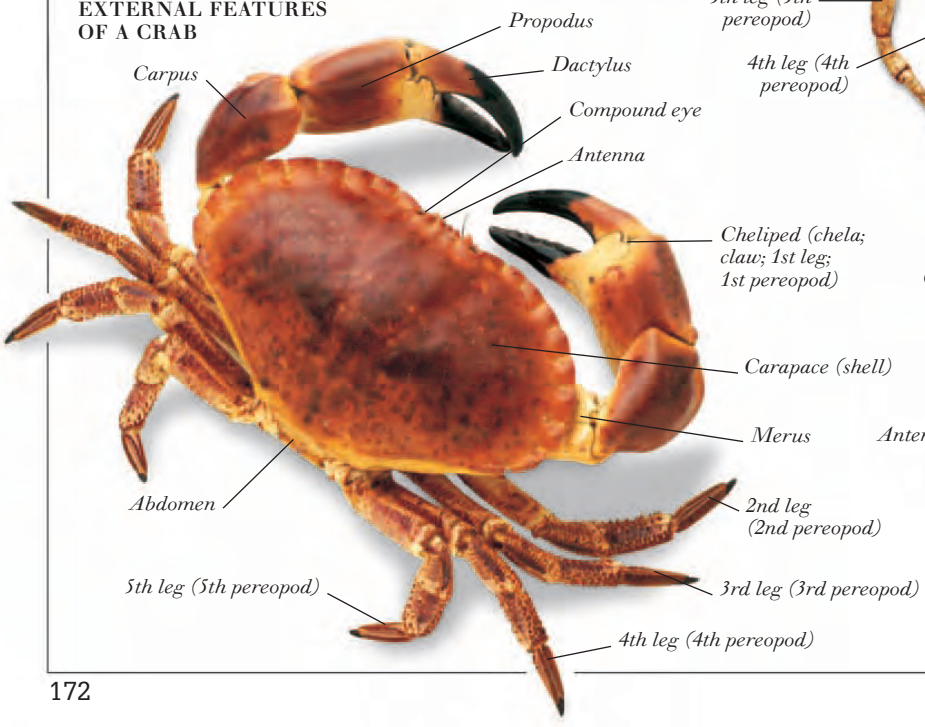
MOLT OF A TARANTULA
Spiders must shed their exoskeleton (external skeleton) to grow. During molting, the exoskeleton splits and the spider pulls itself out, leaving behind the old exoskeleton, shown above.

Crustaceans

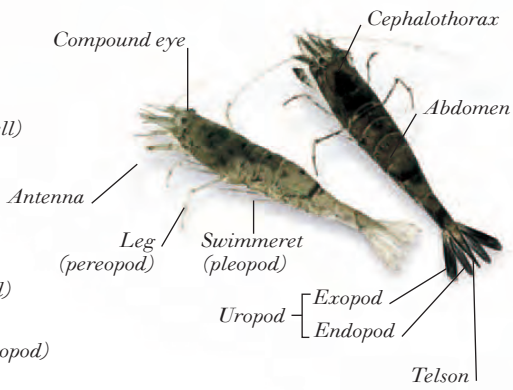
THE SUBPHYLUM CRUSTACEA is one of the largest groups in the phylum Arthropoda. The subphylum is divided into several classes, the most important of which are Malacostraca and Cirripedia. The class Malacostraca includes crayfish, crabs, lobsters, and shrimps. Typical features of malacostracans include a body divided into two sections (a combined head and thorax called a cephalothorax, and an abdomen); an exoskeleton (external skeleton) with a large plate (carapace) covering the cephalothorax; stalked, compound eyes; and two pairs of antennae. The class Cirripedia includes barnacles, which, unlike other crustaceans, spend their adult lives attached to a surface, such as a rock. Other characteristics of cirripedes include an exoskeleton of overlapping calcareous plates; a body consisting almost entirely of thorax (the abdomen and head are minute); and six pairs of thoracic appendages (cirri) used for filter feeding.

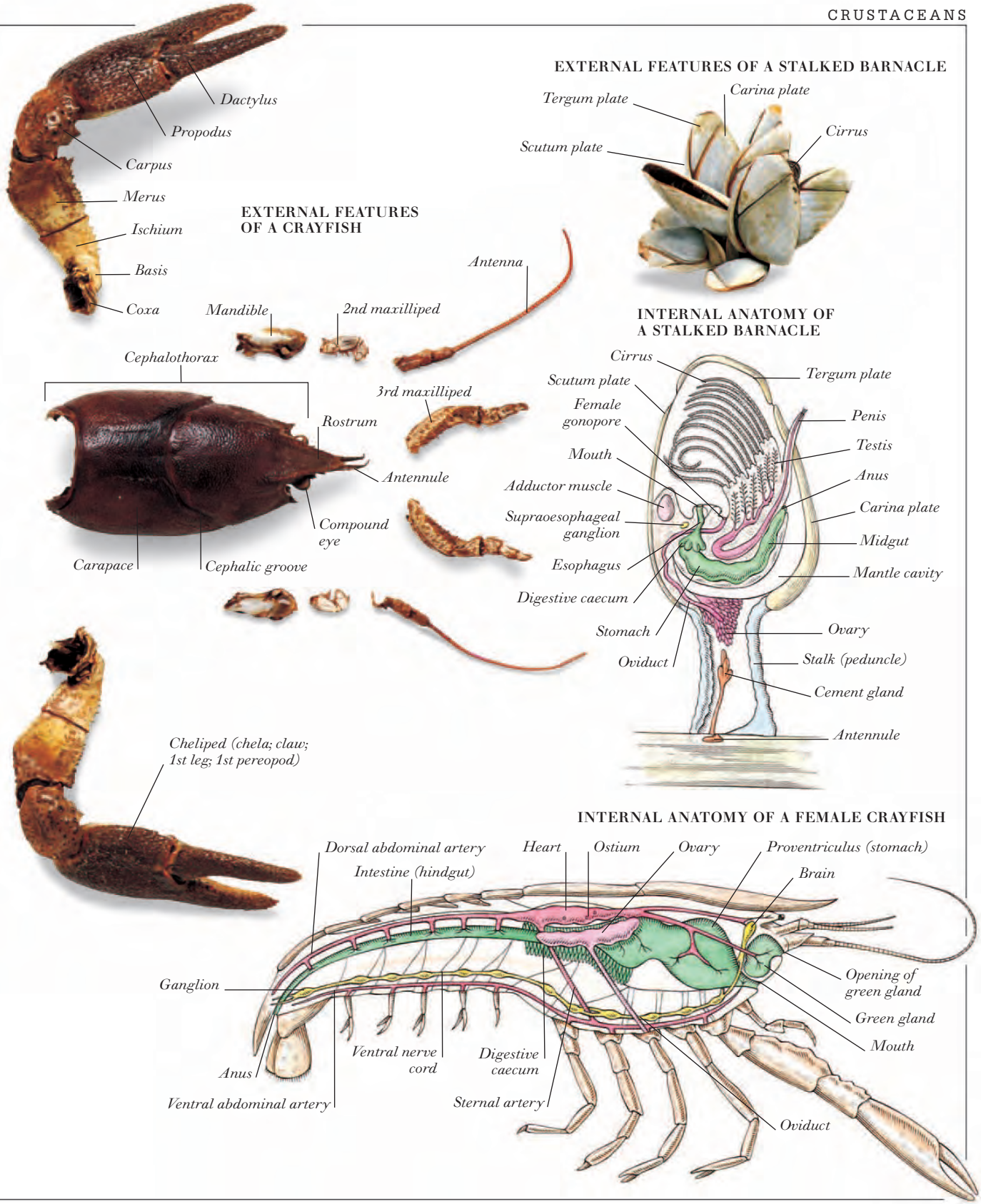


EXTERNAL FEATURES OF A CRAB



EXTERNAL FEATURES OF A SHRIMP

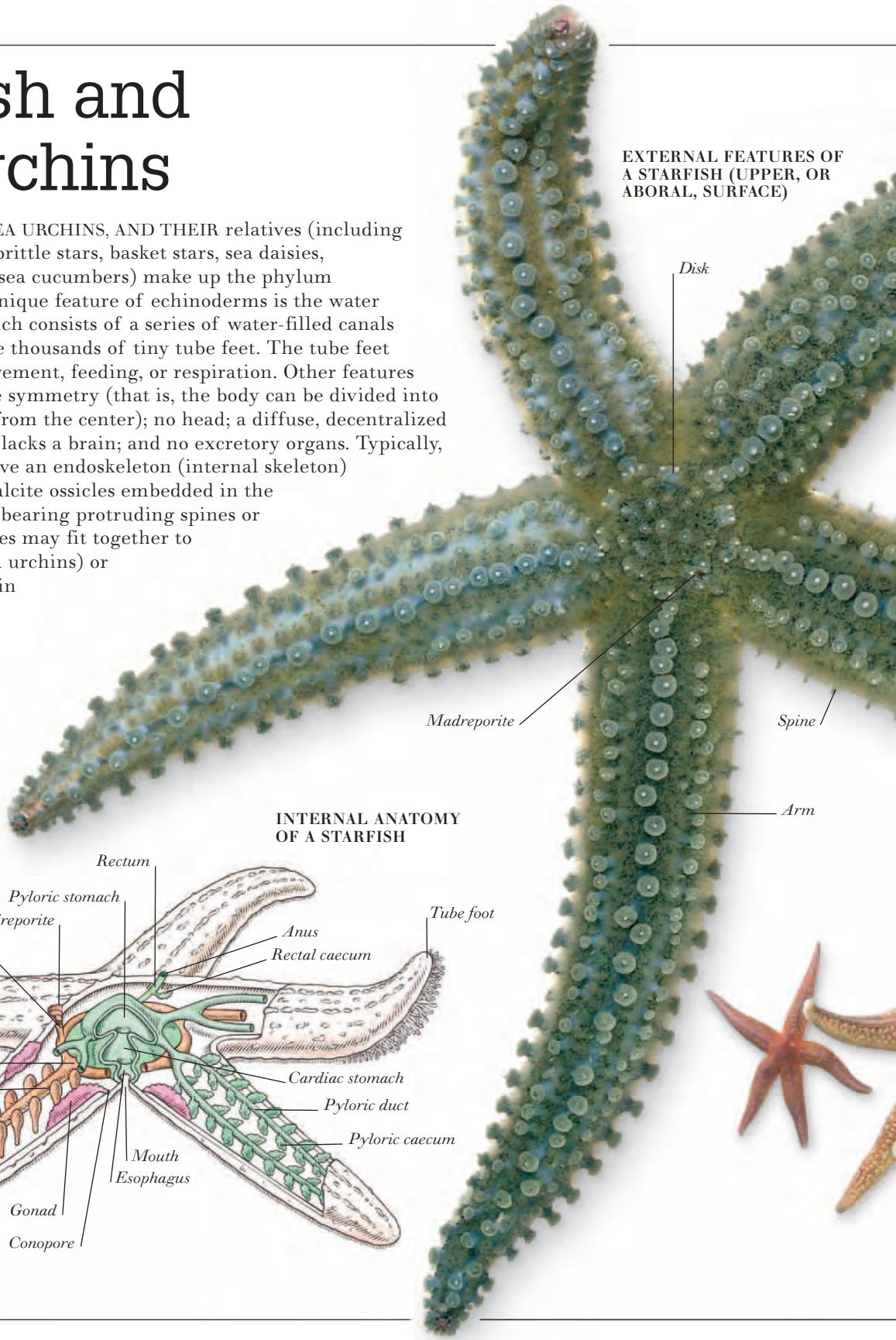



EXTERNAL FEATURES OF A STALKED BARNACLE
Tergum plate
Carina plate
Cirrus
Scutum plate
EXTERNAL FEATURES OF A CRAYFISH
Dactylus
Propodus
Carpus
Merus
Ischium
Basis
Coxa
Antenna
Mandible
2nd maxilliped
3rd maxilliped
Cephalothorax
Rostrum
Antennule
Compound eye
Carapace
Cephalic groove
INTERNAL ANATOMY OF A STALKED BARNACLE
Cirrus
Tergum plate
Scutum plate
Female gonopore
Penis
Testis
Mouth
Anus
Adductor muscle
Carina plate
Supraoesophageal ganglion
Midgut
Esophagus
Mantle cavity
Digestive caecum
Stomach
Ovary
Oviduct
Stalk (peduncle)
Cement gland
Antennule
Cheliped (chela; claw; 1st leg; 1st pereopod)
INTERNAL ANATOMY OF A FEMALE CRAYFISH
Dorsal abdominal artery
Heart
Ostium
Ovary
Proventriculus (stomach)
Intestine (hindgut)
Brain
Opening of green gland
Ganglion
Green gland
Mouth
Ventral nerve cord
Digestive caecum
Anus
Sternal artery
Ventral abdominal artery
Oviduct

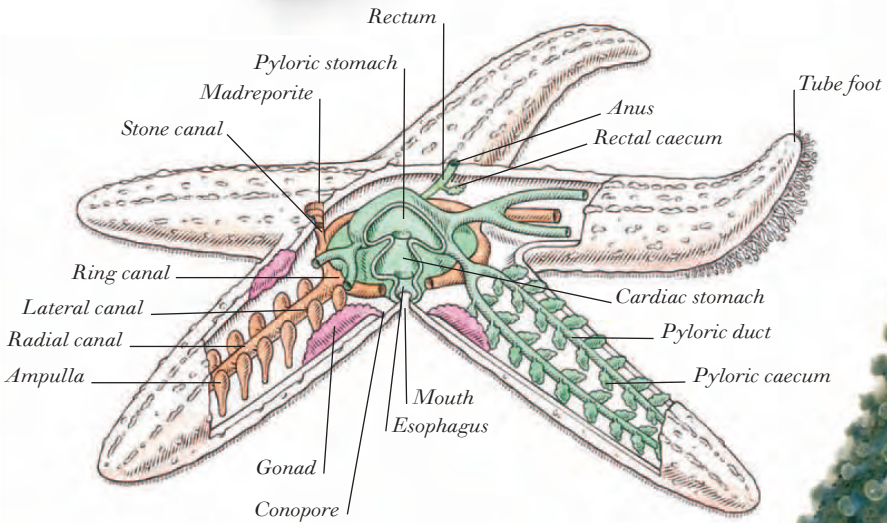
Starfish and sea urchins

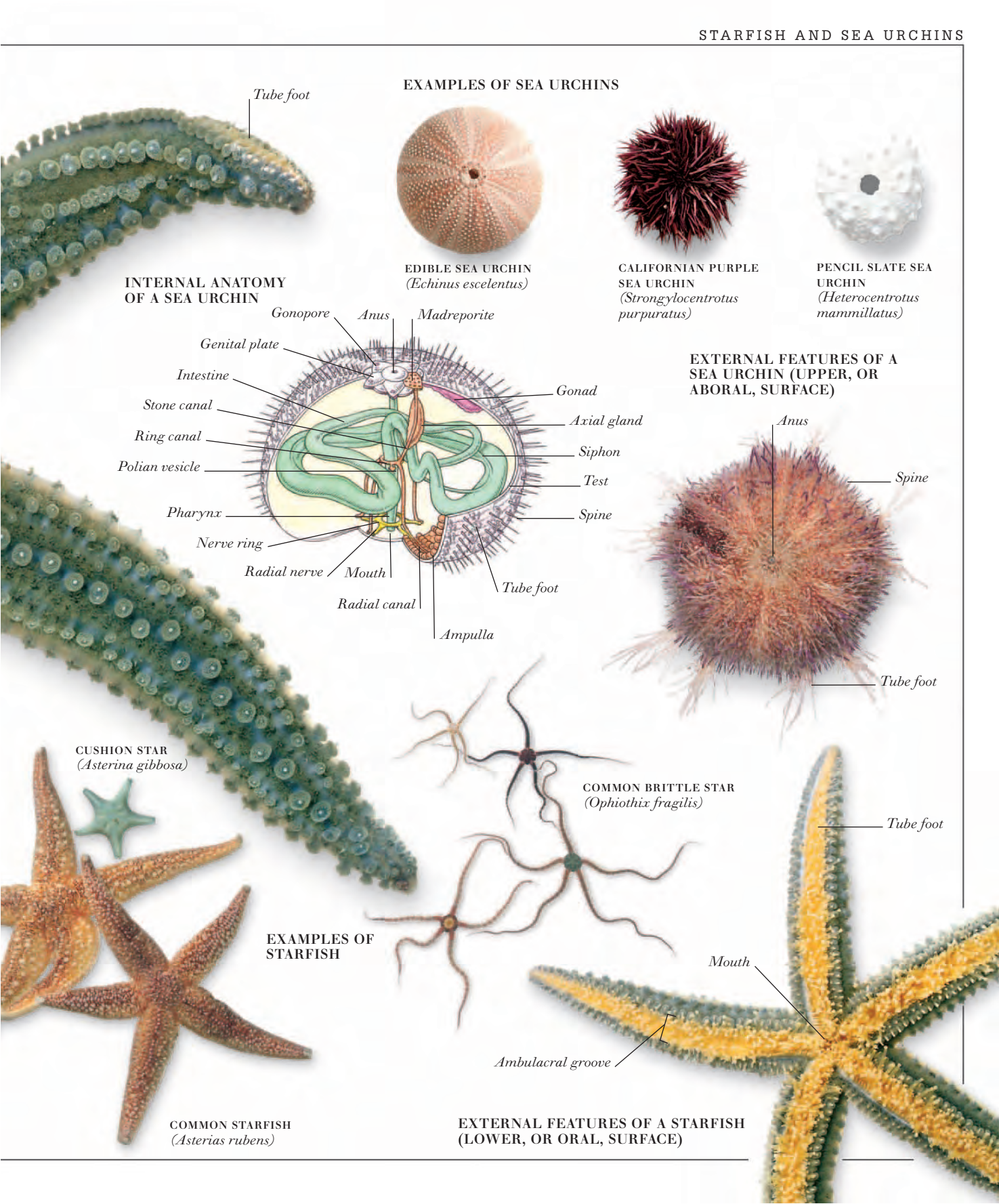
STARFISH, SEA URCHINS, AND THEIR relatives (including feather stars, brittle stars, basket stars, sea daisies, sea lilies, and sea cucumbers) make up the phylum Echinodermata. A unique feature of echinoderms is the water vascular system, which consists of a series of water-filled canals from which protrude thousands of tiny tube feet. The tube feet may be used for movement, feeding, or respiration. Other features include pentaradiate symmetry (that is, the body can be divided into five parts radiating from the center); no head; a diffuse, decentralized nervous system that lacks a brain; and no excretory organs. Typically, echinoderms also have an endoskeleton (internal skeleton) consisting of hard calcite ossicles embedded in the body wall and often bearing protruding spines or tubercles. The ossicles may fit together to form a test (as in sea urchins) or remain separate (as in sea cucumbers).

EXTERNAL FEATURES OF A STARFISH (UPPER, OR ABORAL, SURFACE)



INTERNAL ANATOMY OF A STARFISH

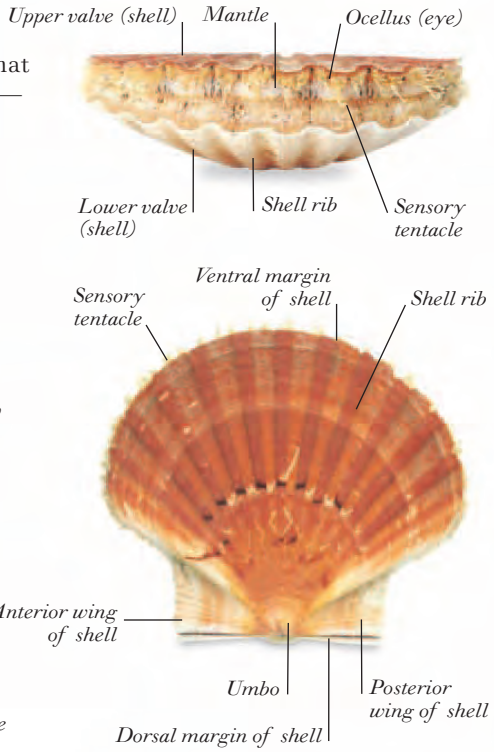



Tube foot
EXAMPLES OF SEA URCHINS
EDIBLE SEA URCHIN
(Echinus escelentus)
CALIFORNIAN PURPLE SEA URCHIN
(Strongylocentrotus purpuratus)
PENCIL SLATE SEA URCHIN
(Heterocentrotus mammillatus)
INTERNAL ANATOMY OF A SEA URCHIN
Gonopore
Anus
Madreporite
Genital plate
Intestine
Stone canal
Ring canal
Polian vesicle
Pharynx
Nerve ring
Radial nerve
Mouth
Radial canal
Ampulla
Gonad
Axial gland
Siphon
Test
Spine
Tube foot
EXTERNAL FEATURES OF A SEA URCHIN (UPPER, OR ABORAL, SURFACE)
Anus
Spine
Tube foot
CUSHION STAR
(Asterina gibbosa)
COMMON BRITTLE STAR
(Ophiothix fragilis)
Tube foot
EXAMPLES OF STARFISH
Mouth
Ambulacral groove
COMMON STARFISH
(Asterias rubens)
EXTERNAL FEATURES OF A STARFISH (LOWER, OR ORAL, SURFACE)

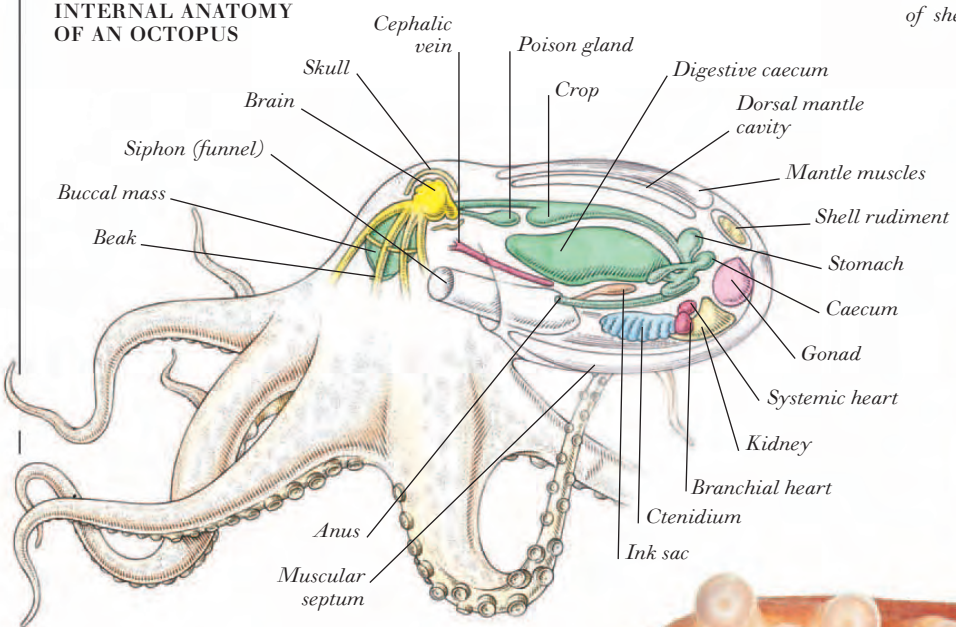
Mollusks

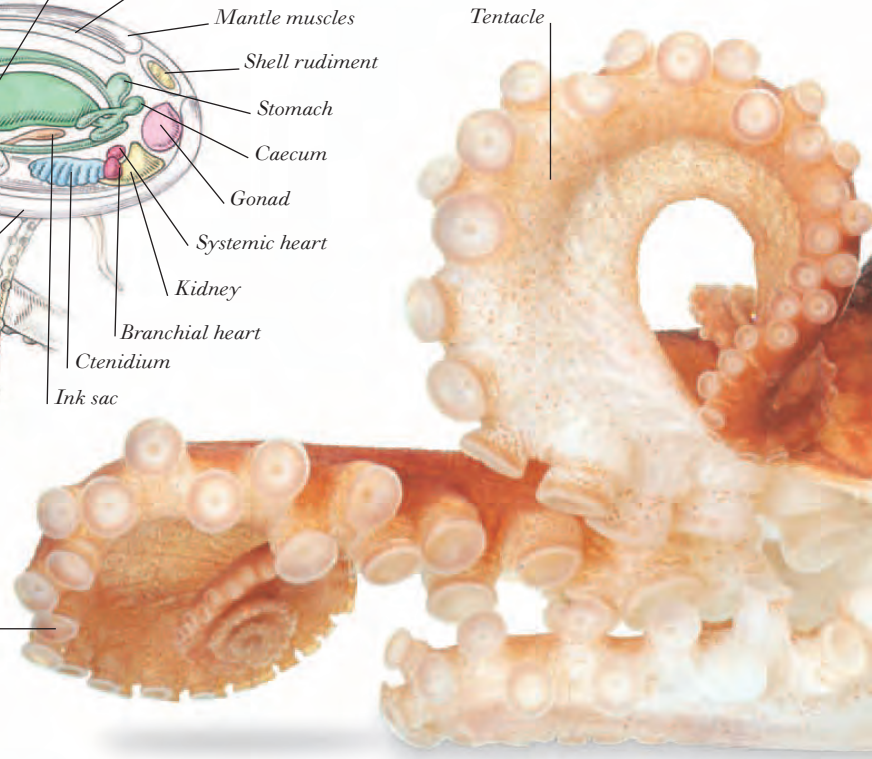
THE PHYLUM MOLLUSCA (MOLLUSKS) is a large group of animals that includes octopuses, snails, and scallops. Octopuses and their relatives—including squid and cuttlefish—form the class Cephalopoda. Cephalopods typically have a head with a radula (a filelike feeding organ) and beak; a well-developed nervous system; sucker-bearing tentacles; a muscular mantle (part of the body wall) that can expel water through the siphon, enabling movement by jet propulsion; and a small shell or no shell. Snails and their relatives—including slugs, limpets, and abalones—make up the class Gastropoda. Gastropods typically have a coiled external shell, although some, such as slugs, have a small internal shell or no shell; a flat foot; and a head with tentacles and a radula. Scallops and their relatives—including clams, mussels, and oysters—make up the class Bivalvia (also called Pelecypoda). Features of bivalves include a shell with two halves (valves); large gills that are used for breathing and filter feeding; and no radula.

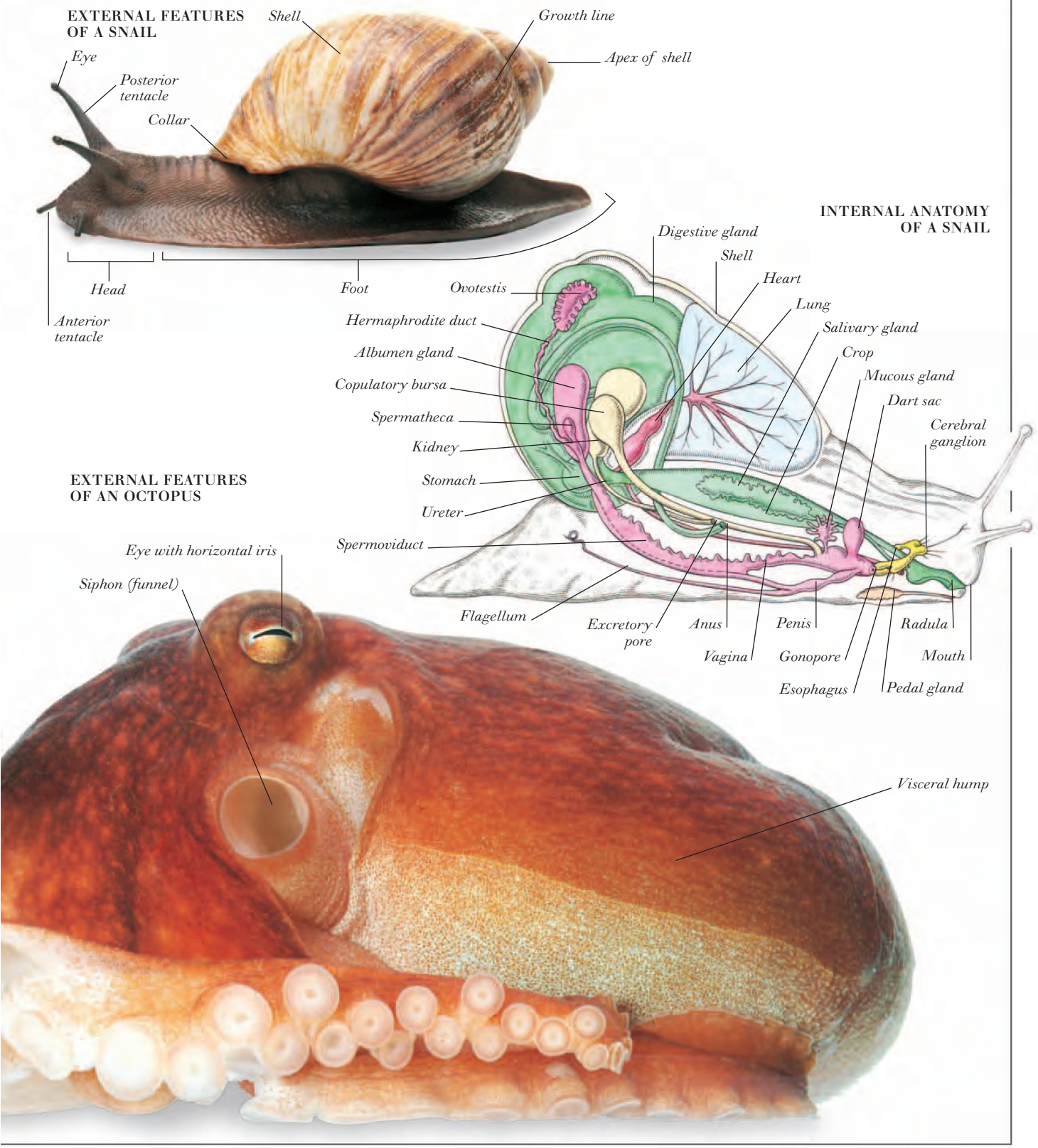
EXTERNAL FEATURES OF A SCALLOP



INTERNAL ANATOMY OF AN OCTOPUS

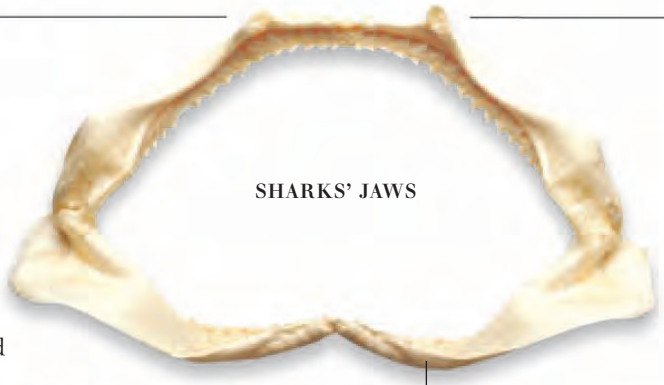


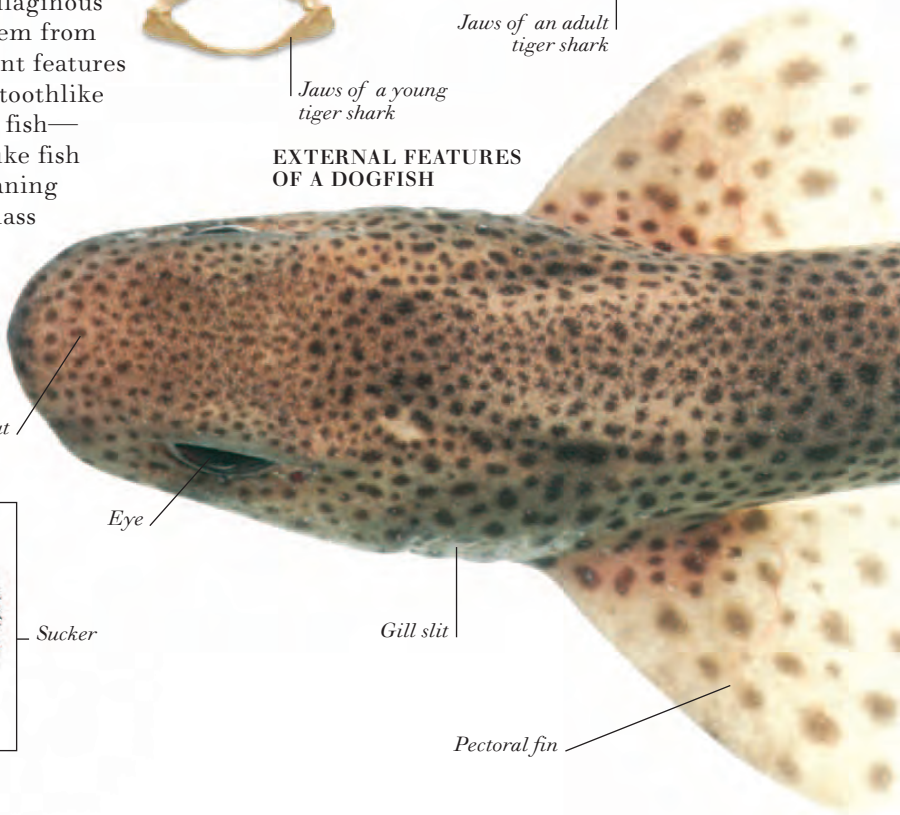


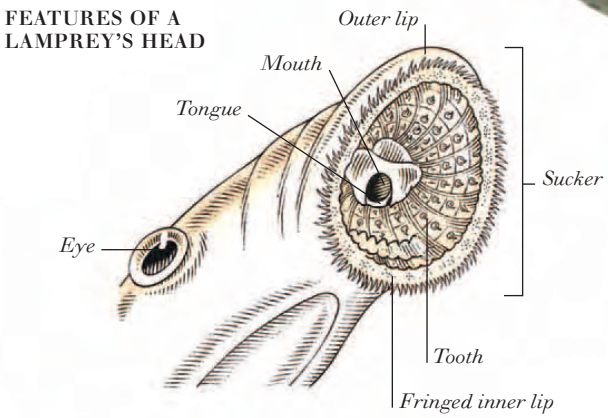

EXTERNAL FEATURES OF A SNAIL
Shell
Growth line
Eye
Apex of shell
Posterior tentacle
Collar
Head
Foot
Anterior tentacle
INTERNAL ANATOMY OF A SNAIL
Digestive gland
Shell
Heart
Ovotestis
Lung
Hermaphrodite duct
Salivary gland
Albumen gland
Crop
Copulatory bursa
Mucous gland
Spermatheca
Dart sac
Kidney
Cerebral ganglion
Stomach
Ureter
Spermoviduct
Flagellum
Excretory pore
Anus
Penis
Radula
Vagina
Gonopore
Mouth
Esophagus
Pedal gland
EXTERNAL FEATURES OF AN OCTOPUS
Eye with horizontal iris
Siphon (funnel)
Visceral hump

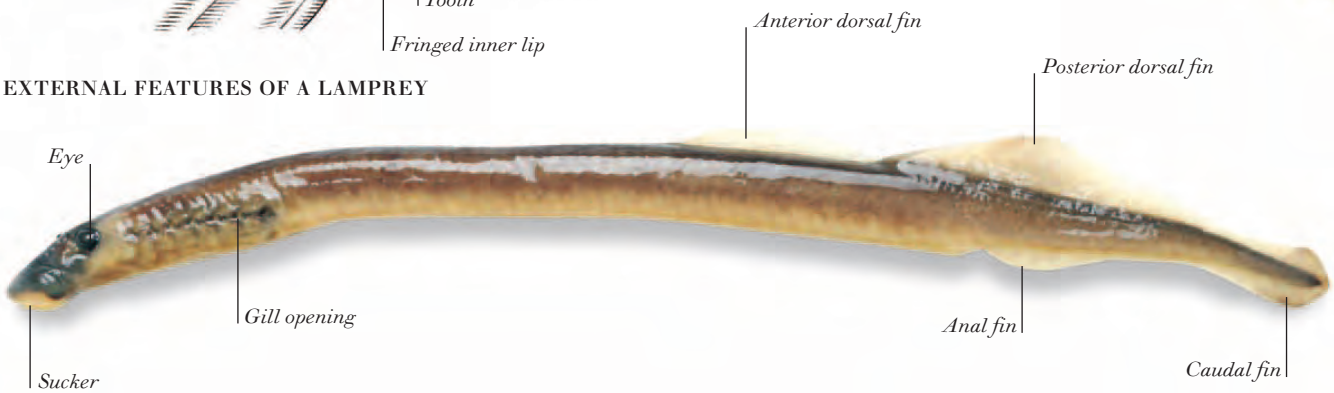
Sharks and jawless fish

SHARKS, DOGFISH (WHICH ARE actually small sharks), skates, and rays belong to a class of fishes called Chondrichthyes, which is a division of the superclass Gnathostomata (meaning "jawed mouths"). Also sometimes known as elasmobranchs, sharks and their relatives have a skeleton made of cartilage (hence their common name, cartilaginous fish), a characteristic that distinguishes them from bony fish (see pp. 180-181). Other important features of cartilaginous fish are extremely tough, toothlike scales, and lack of a swim bladder. Jawless fish—lampreys and hagfish—are primitive, eellike fish that make up the order Cyclostomata (meaning "round mouths"), a division of the superclass Agnatha (meaning "without jaws"). In addition to their characteristic round, suckerlike mouths and lack of jaws, cyclostomes also have smooth, slimy skin without scales, and unpaired fins.

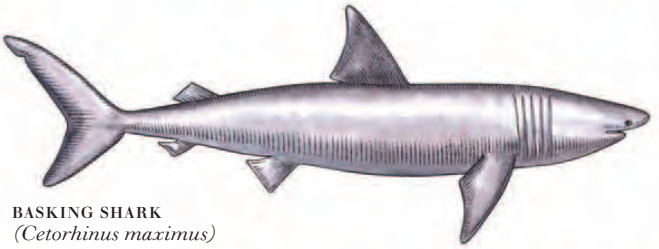








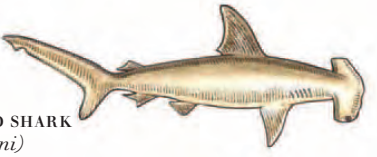
EXAMPLES OF CARTILAGINOUS FISH



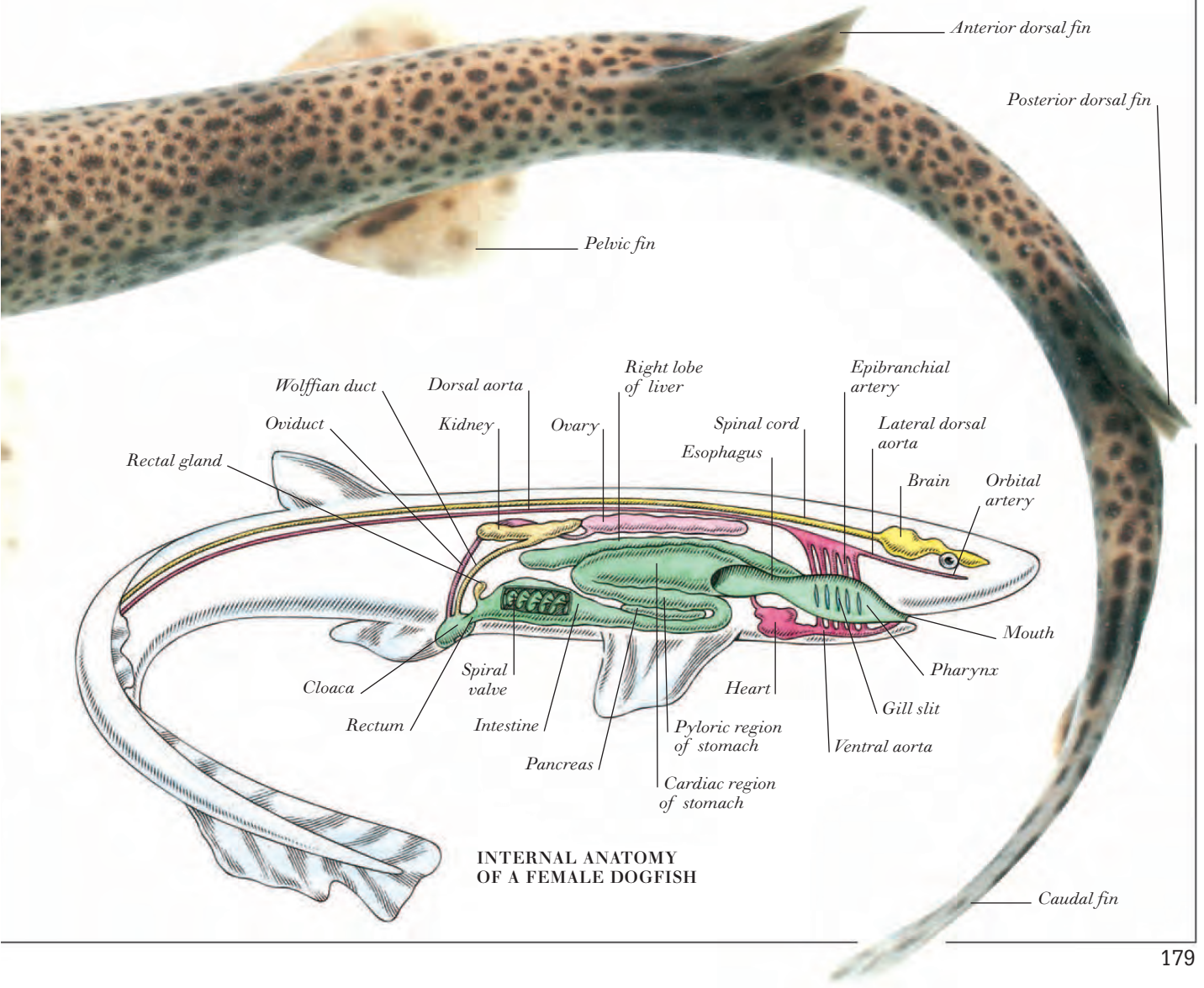
BASKING SHARK
(Cetorhinus maximus)

TIGER SHARK
(Galeocerdo cuvier)

THORNBACK RAY
(Raja clavata)



SCALLOPED
HAMMERHEAD SHARK
(Sphyrna lewini)



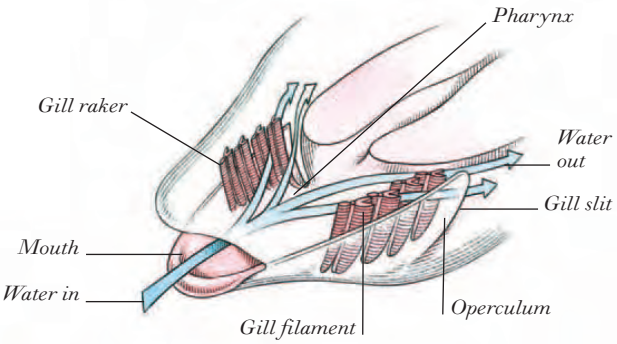
INTERNAL ANATOMY OF A FEMALE DOGFISH

Bony fish

BONY FISH, SUCH AS CARP, TROUT, SALMON, perch, and cod, are by far the best known and largest group of fish, with more than 20,000 species (over 95 percent of all known fish). As their name suggests, bony fish have skeletons made of bone, in contrast to the cartilaginous skeletons of sharks, jawless fish, and their relatives (see pp. 178-179). Other typical features of bony fish include a swim bladder, which functions as a variable-buoyancy organ, enabling a fish to remain effortlessly at whatever depth it is swimming; relatively thin, bonelike scales; a flap (called an operculum) covering the gills; and paired pelvic and pectoral fins. Scientifically, bony fish belong to the class Osteichthyes, which is a division of the superclass Gnathostomata (meaning "jawed mouths").

HOW FISH BREATHE

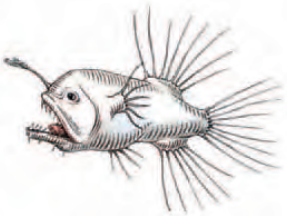
Fish "breathe" by extracting oxygen from water through their gills. Water is sucked in through the mouth; simultaneously, the opercula close to prevent the water from escaping. The mouth is then closed, and muscles in the walls of the mouth, pharynx, and opercular cavity contract to pump the water inside over the gills and out through the opercula. Some fish rely on swimming with their mouths open to keep water flowing over the gills.



EXAMPLES OF BONY FISH

MANDARINFISH
(Synchiropus splendidus)

OCEANIC SEAHORSE
(Hippocampus kuda)

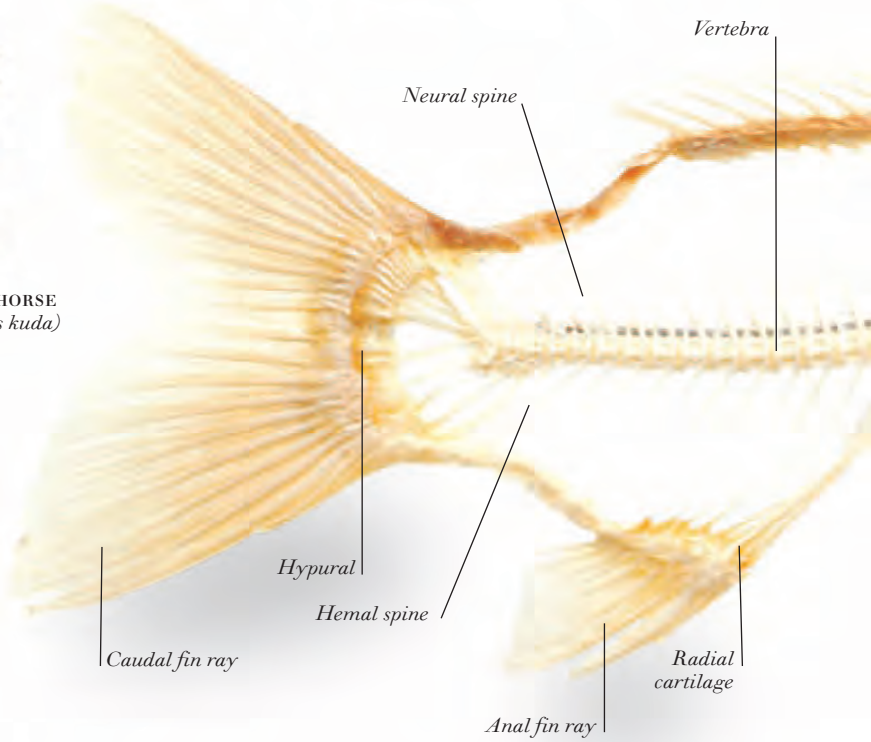


ANGLERFISH
(Caulophryne jordani)

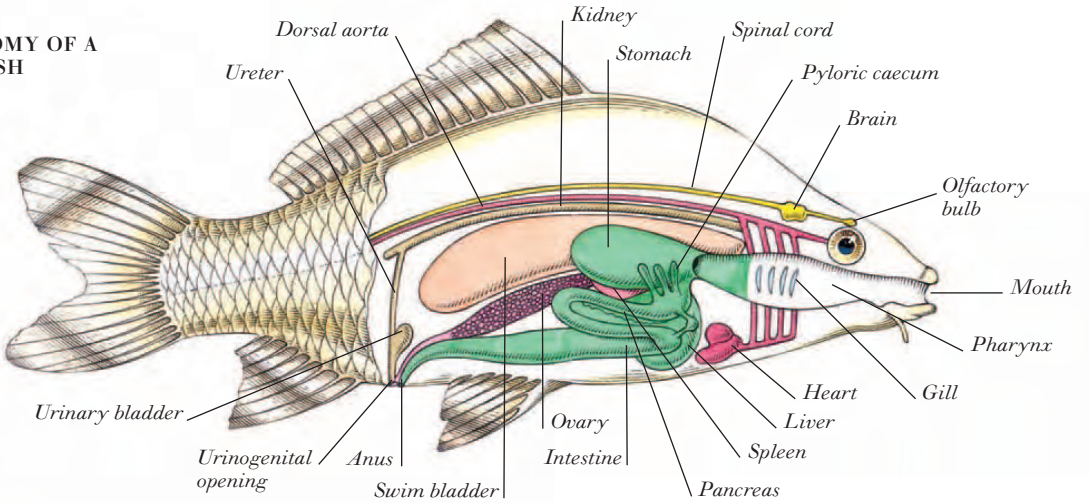
LIONFISH
(Pterois volitans)

STURGEON
(Acipenser sturio)

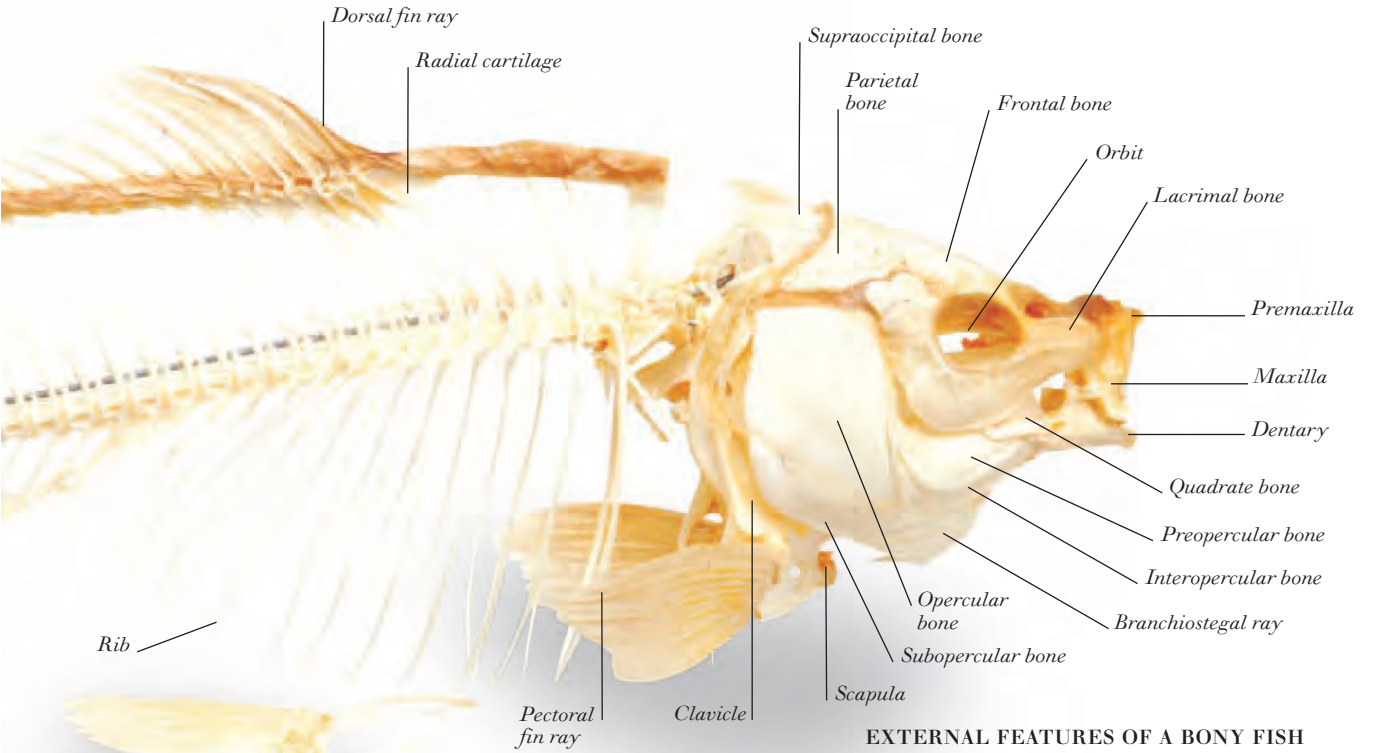
SNOWFLAKE MORAY EEL
(Echidna nebulosa)



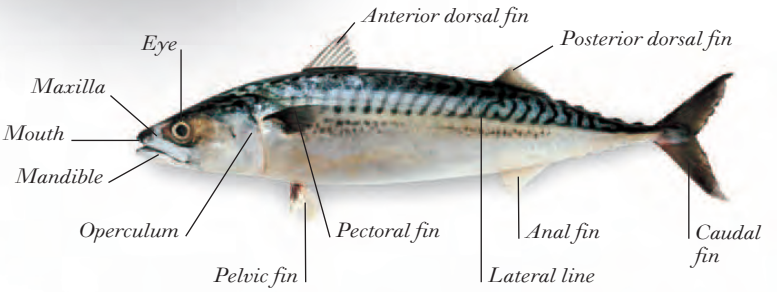
INTERNAL ANATOMY OF A FEMALE BONY FISH



SKELETON OF A BONY FISH



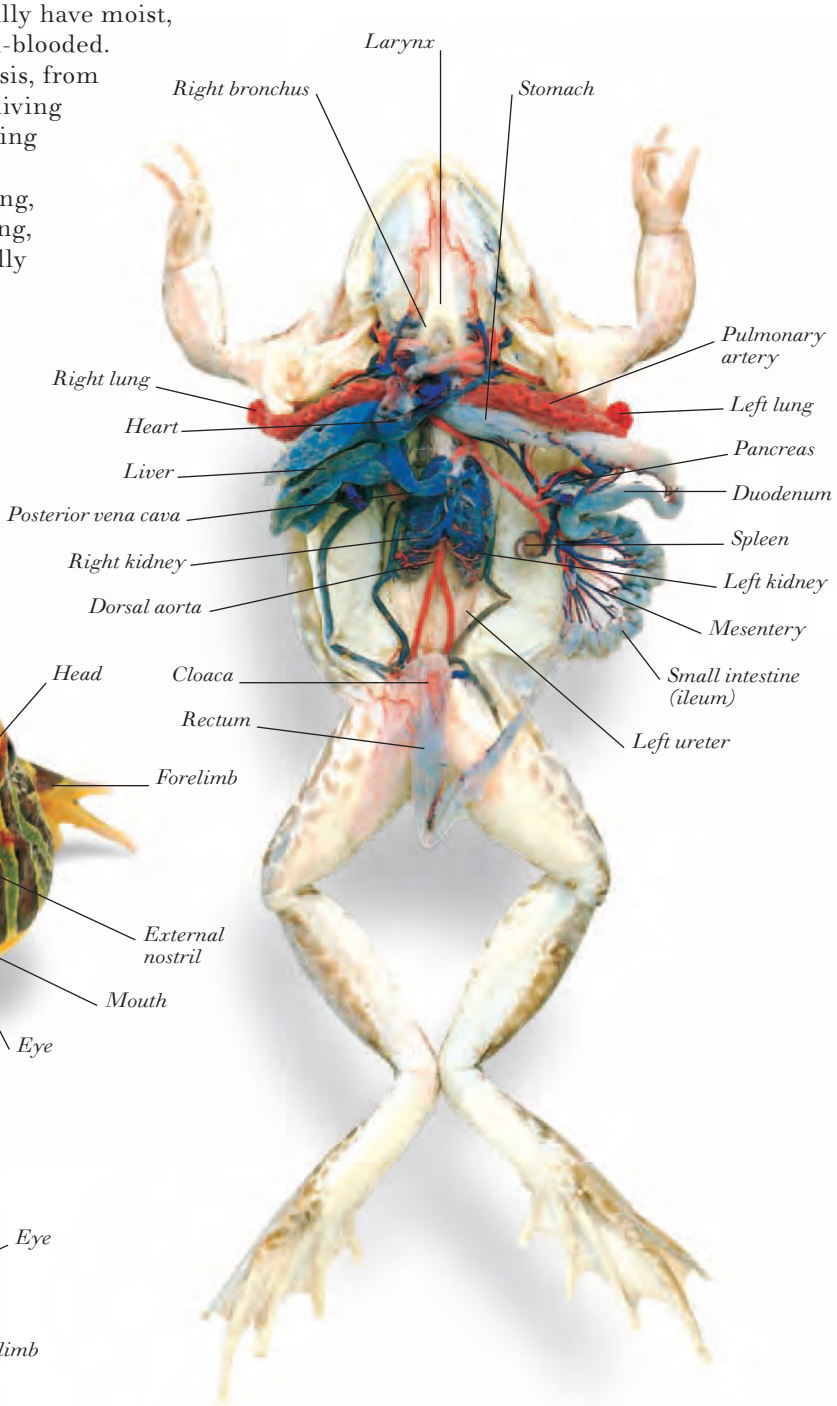
EXTERNAL FEATURES OF A BONY FISH



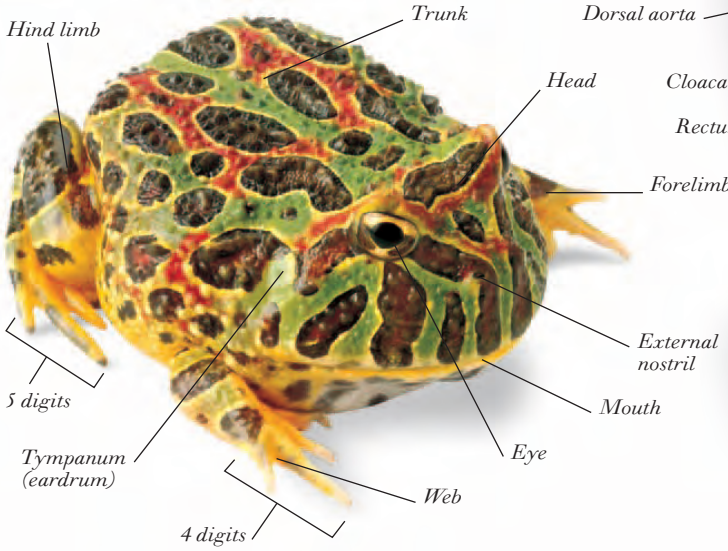
Amphibians

THE CLASS AMPHIBIA INCLUDES FROGS and toads (which make up the order Anura), and newts and salamanders (which make up the order Urodela). Amphibians typically have moist, scaleless, hairless skin; lungs; and are cold-blooded. They also undergo complete metamorphosis, from eggs laid in water through various water-living larval stages (such as tadpoles) to land-living adults. Typical features of adult frogs and toads include a squat body with no tail; long, powerful hind legs; and large, often bulging, eyes. Adult newts and salamanders typically have a long body with a well-developed tail; and relatively short, equal-sized legs. However, newts and salamanders show considerable variation; for example, in some species the adults have minute legs, external gills rather than lungs, and spend their entire lives in water.

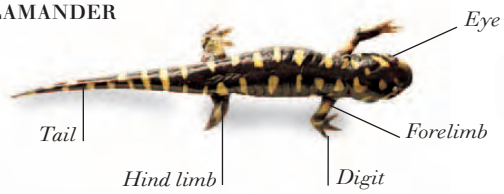
INTERNAL ANATOMY OF A FEMALE FROG



EXTERNAL FEATURES OF A FROG



EXTERNAL FEATURES OF A SALAMANDER



EGGS (SPAWN)

YOUNG TADPOLES

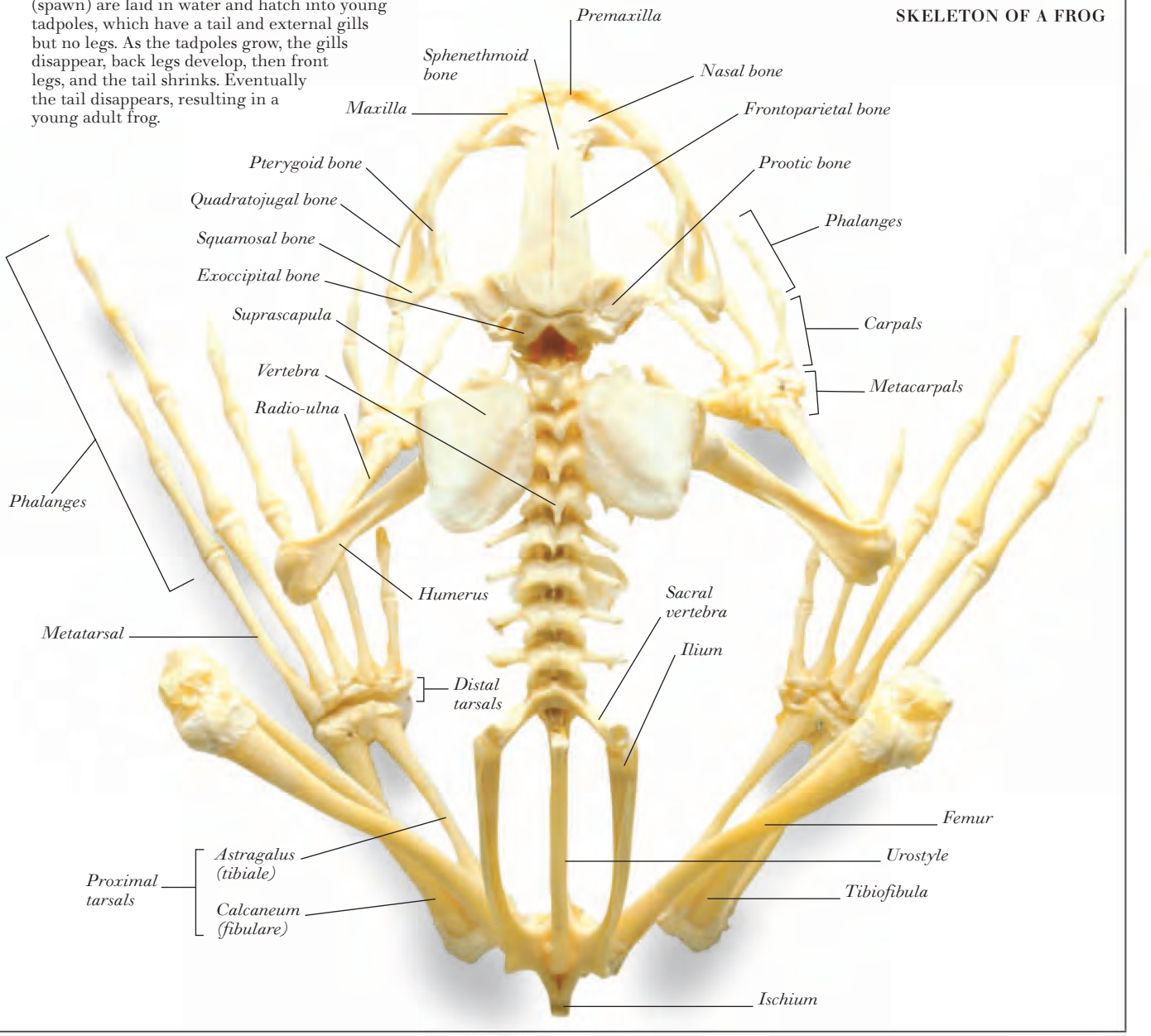
MATURE TADPOLE

YOUNG FROG

METAMORPHOSIS OF FROGS

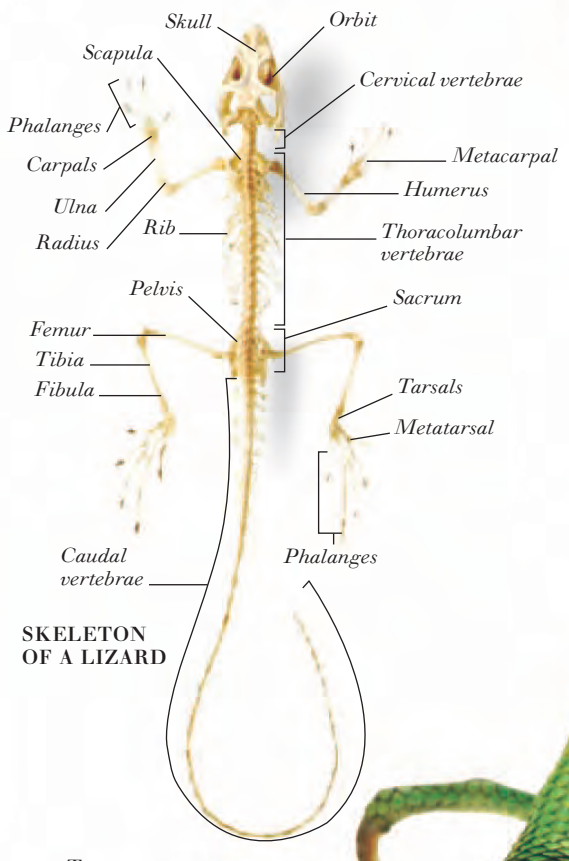
Frogs undergo complete metamorphosis. Eggs (spawn) are laid in water and hatch into young tadpoles, which have a tail and external gills but no legs. As the tadpoles grow, the gills disappear, back legs develop, then front legs, and the tail shrinks. Eventually the tail disappears, resulting in a young adult frog.

SKELETON OF A FROG



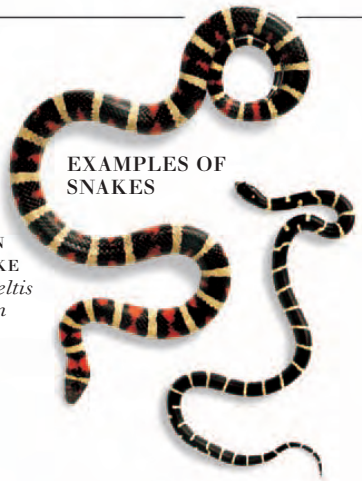
Lizards and snakes

LIZARDS AND SNAKES BELONG to the order Squamata, a division of the class Reptilia. Characteristic reptilian features include scaly skin, lungs, and cold-bloodedness. Most reptiles lay leathery-shelled eggs, although some hatch the eggs inside their bodies and give birth to live young. Lizards belong to the suborder Lacertilia. Typically, they have long tails, and shed their skin in several pieces. Many lizards can regenerate a tail if it is lost; some can change color; and some are limbless. Snakes make up the suborder Ophidia (also called Serpentes). All snakes have long, limbless bodies; can dislocate their lower jaw to swallow large prey; and have eyelids that are joined together to form a single transparent covering over the front of the eye. Most snakes shed their skin in a single piece. Constrictor snakes kill their prey by squeezing; venomous snakes poison their prey.



SKELETON OF A LIZARD

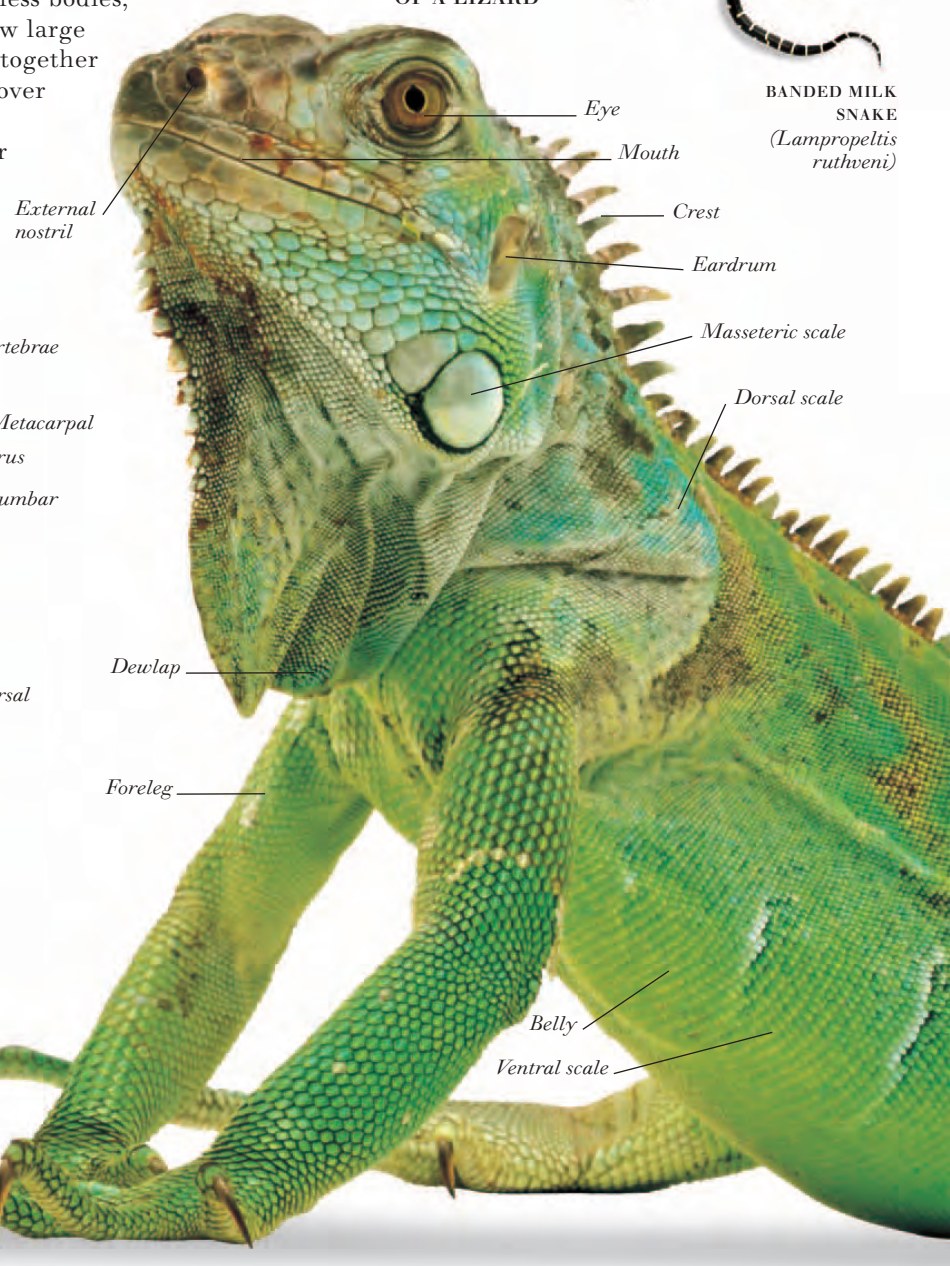
EXAMPLES OF SNAKES

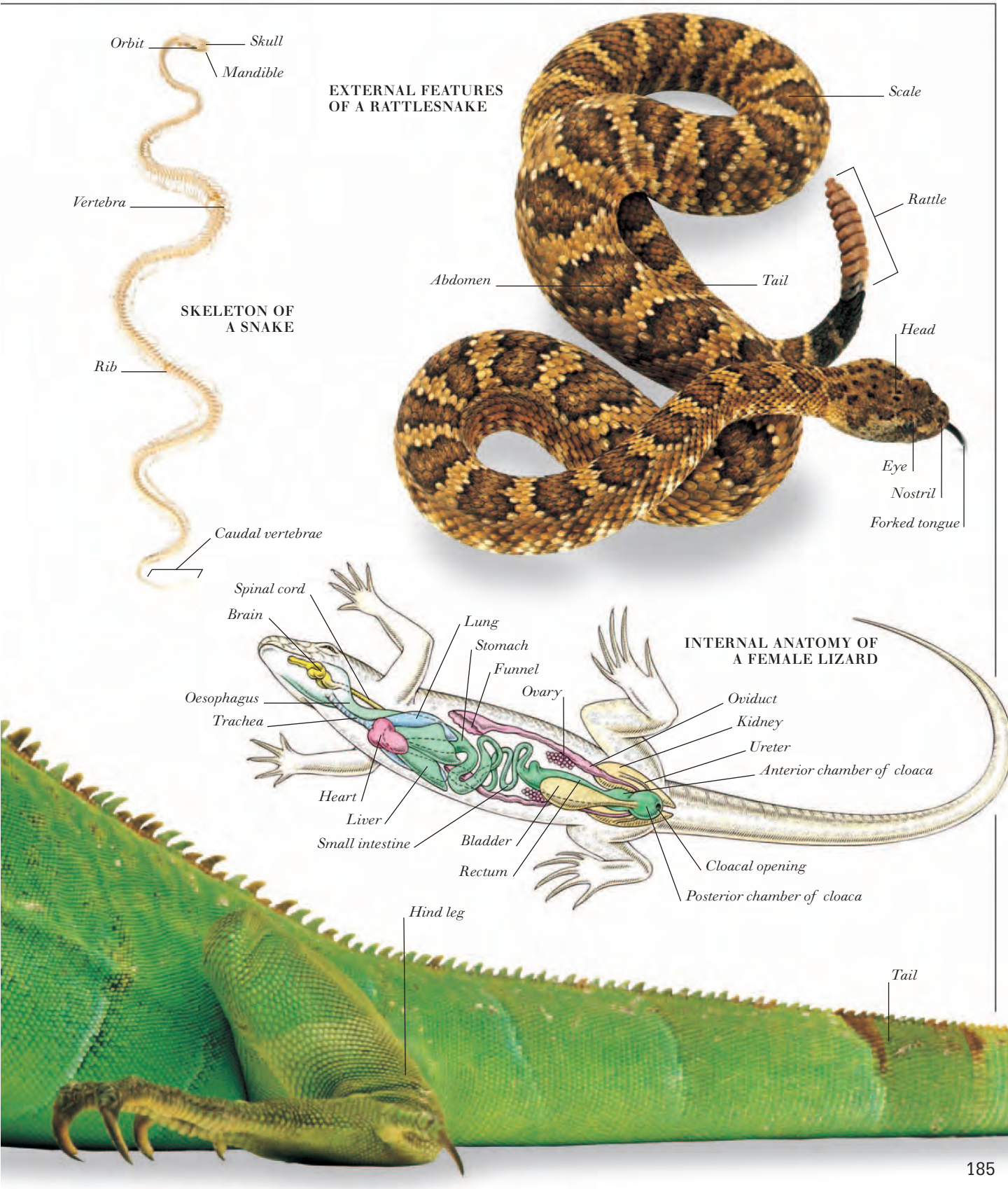


MEXICAN MOUNTAIN KING SNAKE *(Lampropeltis triangulum annulata)*

BANDED MILK SNAKE *(Lampropeltis ruthveni)*

EXTERNAL FEATURES OF A LIZARD




Orbit
Skull
Mandible
Vertebra
Rib
Caudal vertebrae
SKELETON OF A SNAKE
EXTERNAL FEATURES OF A RATTLESNAKE
Scale
Rattle
Abdomen
Tail
Head
Eye
Nostril
Forked tongue
Spinal cord
Brain
Lung
Stomach
Funnel
Ovary
Oesophagus
Trachea
Heart
Liver
Small intestine
Bladder
Rectum
INTERNAL ANATOMY OF A FEMALE LIZARD
Oviduct
Kidney
Ureter
Anterior chamber of cloaca
Cloacal opening
Posterior chamber of cloaca
Hind leg
Tail

Crocodilians and turtles

CROCODILIANS AND TURTLES BELONG to different orders in the class Reptilia. The order Crocodilia includes crocodiles, alligators, caimans, and gharials. Typically, crocodilians are carnivores (flesh-eaters), and have a long snout, sharp teeth for gripping prey, and hard, square scales. All crocodilians are adapted to living on land and in water: they have four strong legs for moving on land; a powerful tail for swimming; and their eyes and nostrils are high on the head so that they stay above water while the rest of the body is submerged. The order Chelonia includes marine turtles, terrapins (freshwater turtles), and tortoises (land turtles). Characteristically, chelonians have a short, broad body encased in a bony shell with an outer horny covering, into which the head and limbs can be withdrawn; and a horny beak instead of teeth.

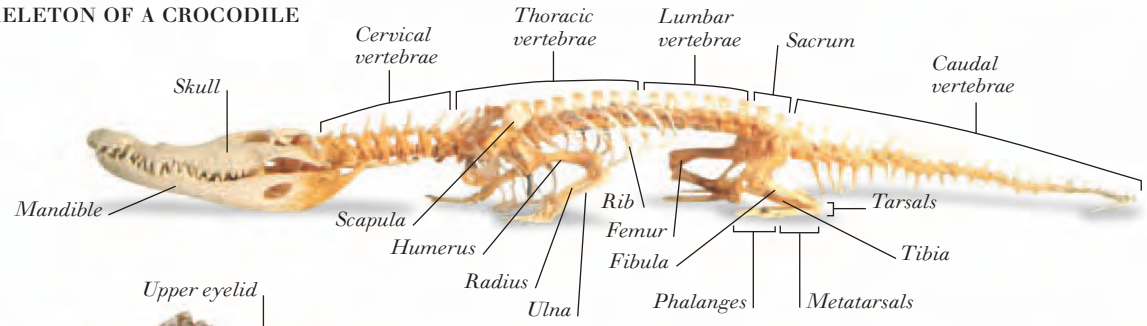
SKULLS OF CROCODILIANS

GHARIAL
(Gavialis gangeticus)

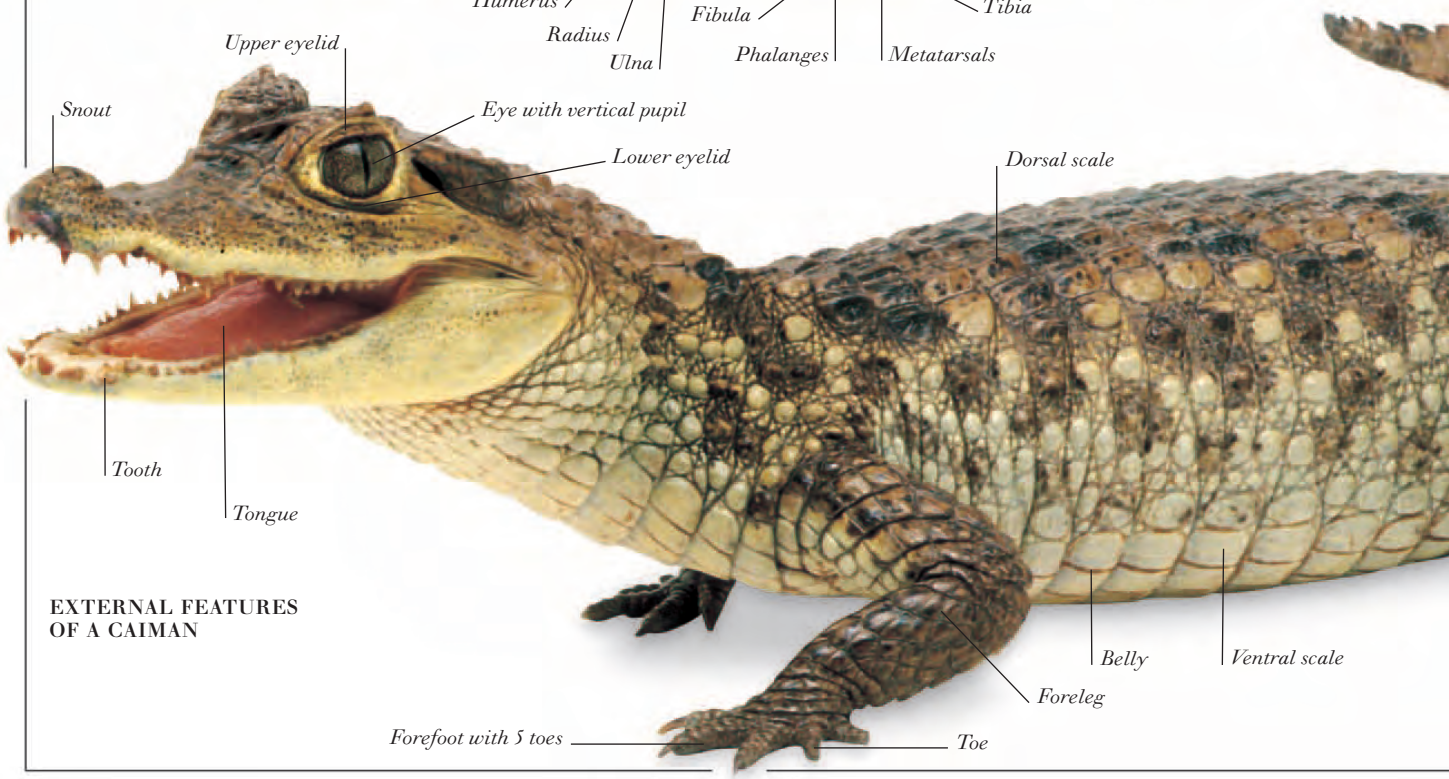
NILE CROCODILE
(Crocodylus niloticus)

AMERICAN ALLIGATOR
(Alligator mississippiensis)

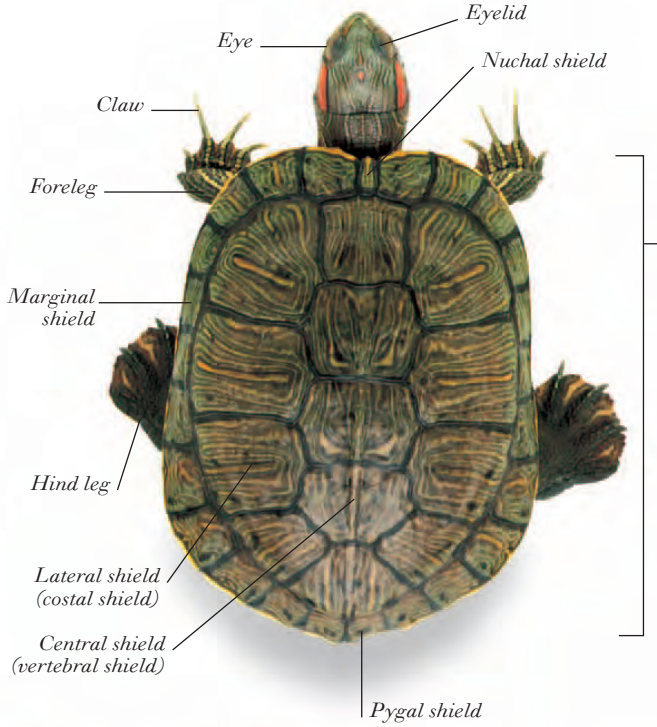
SKELETON OF A CROCODILE



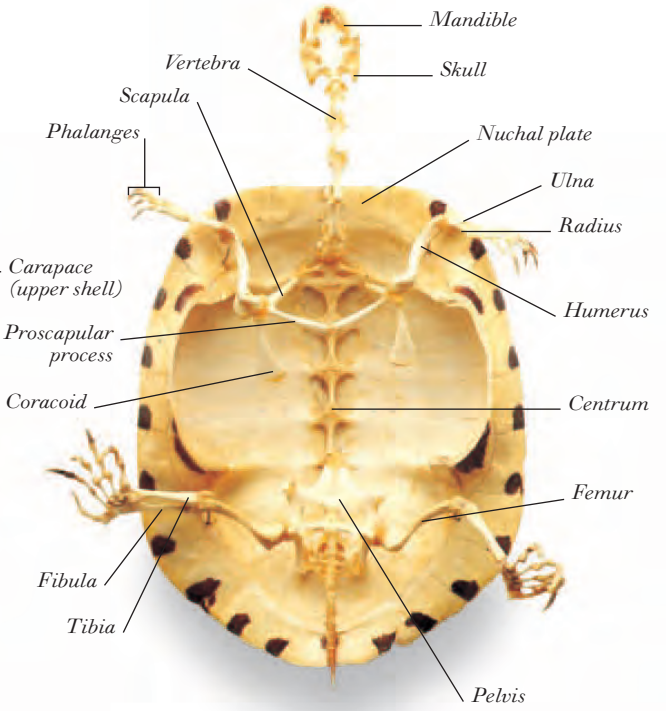
EXTERNAL FEATURES OF A CAIMAN

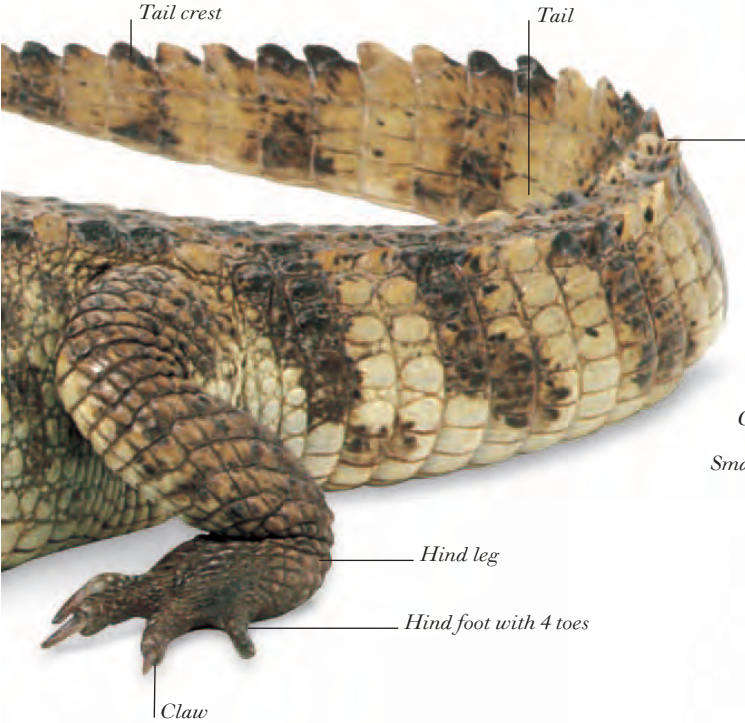


EXTERNAL FEATURES OF A TERRAPIN

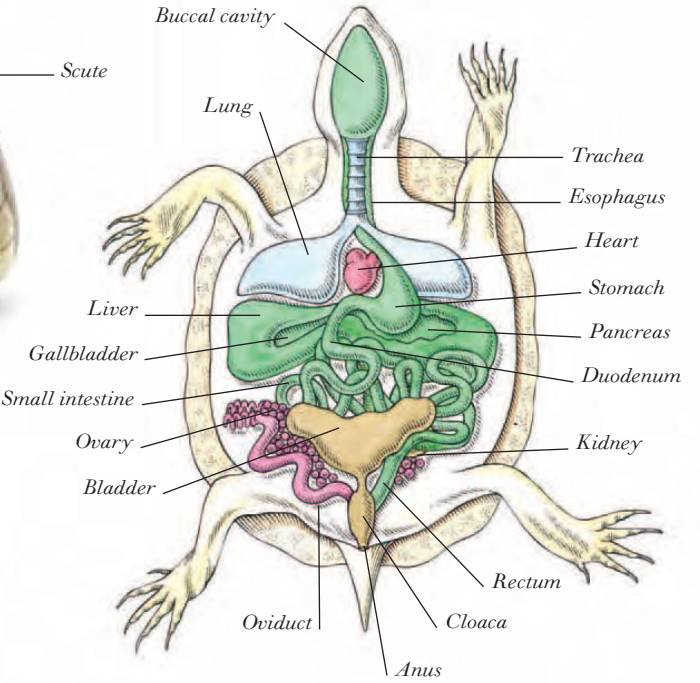


SKELETON OF A TURTLE





INTERNAL ANATOMY OF A FEMALE TORTOISE



Birds 1

BIRDS MAKE UP THE CLASS AVES. There are more than 9,000 species, almost all of which can fly (the only flightless birds are penguins, ostriches, rheas, cassowaries, and kiwis). The ability to fly is reflected in the typical bird features: forelimbs modified as wings; a streamlined body; and hollow bones to reduce weight. All birds lay hard-shelled eggs, which the parents incubate. Birds' beaks and feet vary according to diet and way of life. Beaks range from general-purpose types suitable for a mixed diet (those of thrushes, for example), to types specialized for particular foods (such as the large, curved, sieving beaks of flamingos). Feet range from the webbed "paddles" of ducks, to the talons of birds of prey. Plumage also varies widely, and in many species the male is brightly colored for courtship display whereas the female is drab.

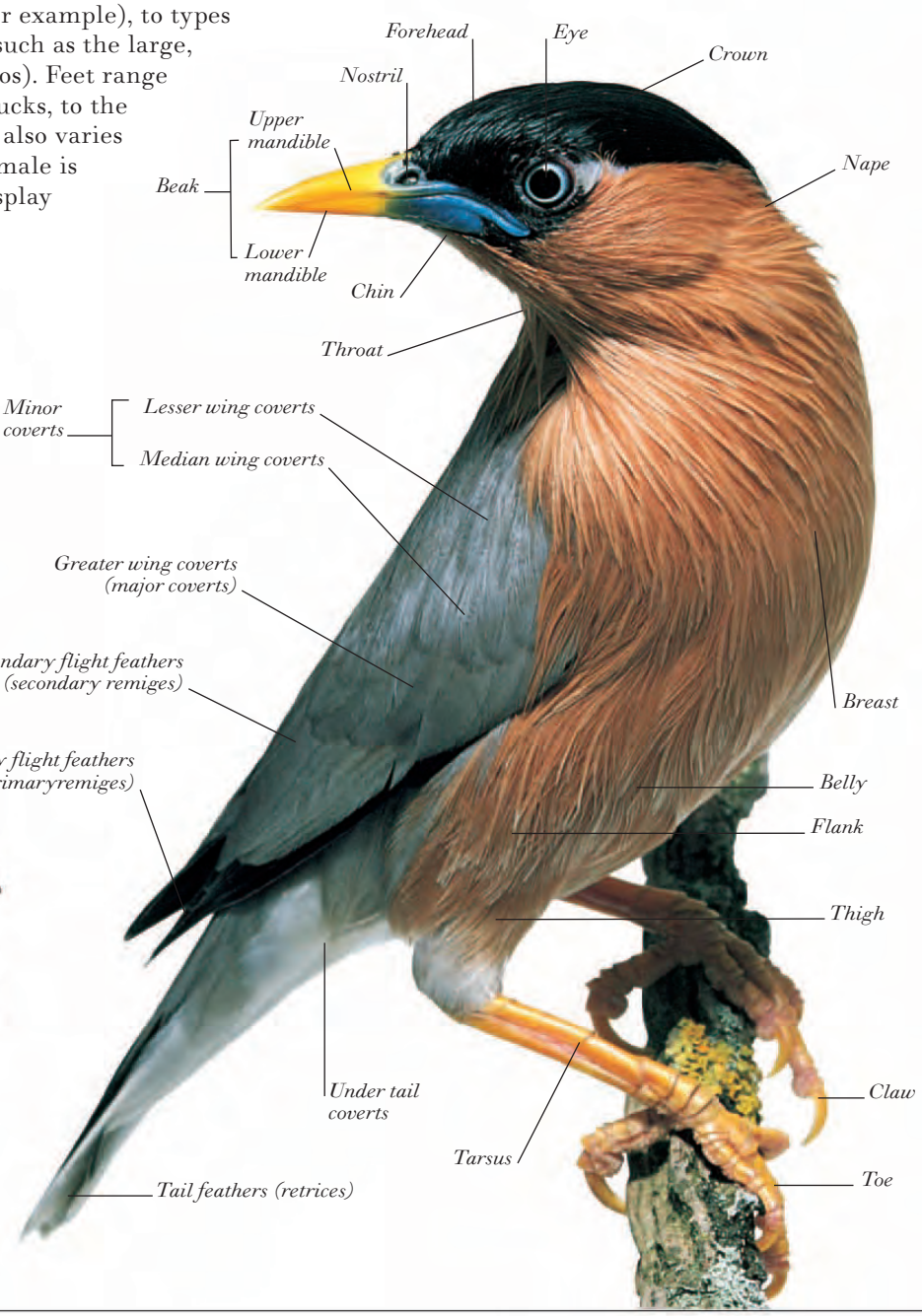
EXAMPLES OF BIRDS

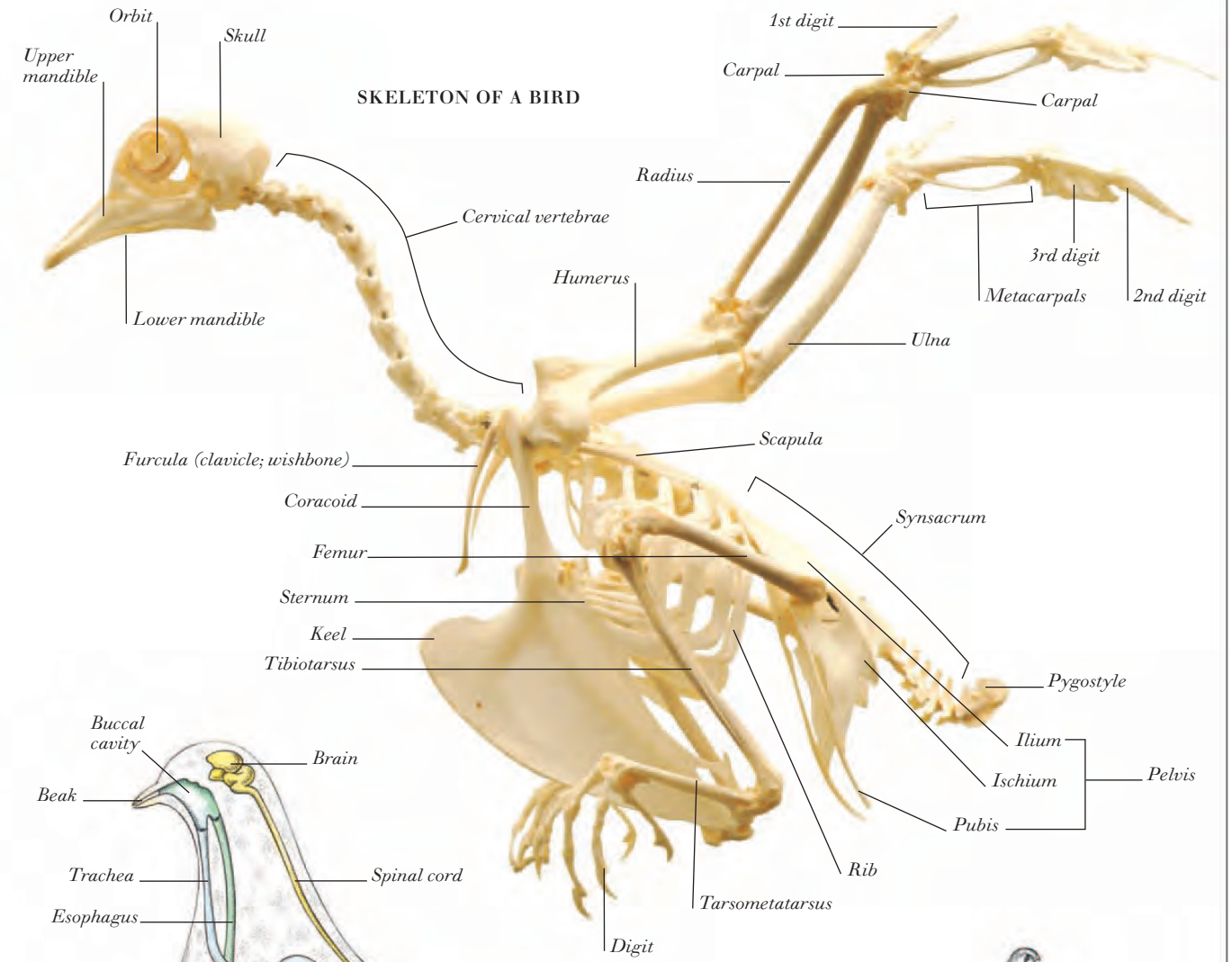
MALE TUFTED DUCK
(Aythya fuligula)

WHITE STORK
(Ciconia ciconia)

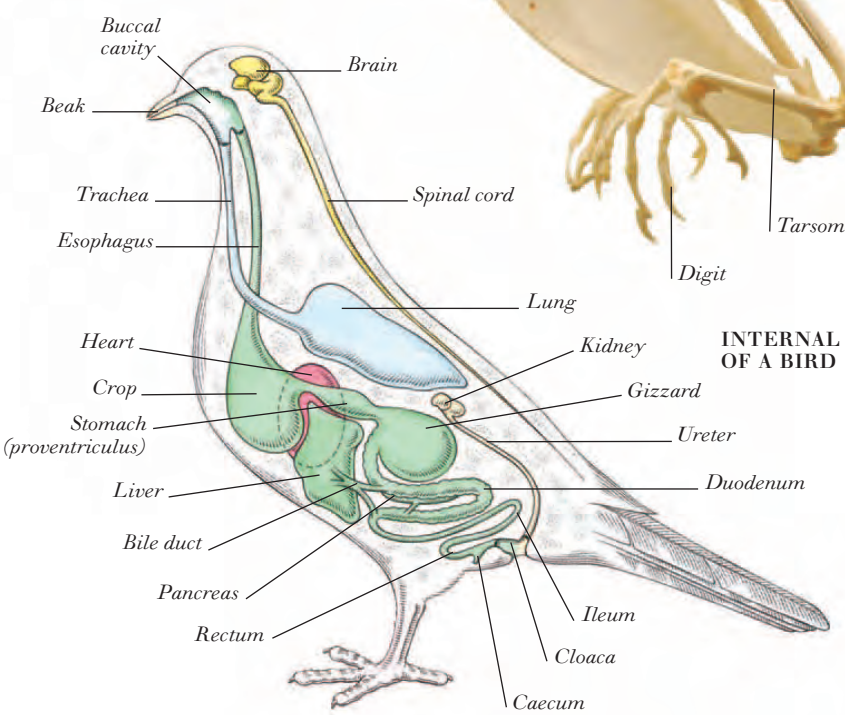
MALE OSTRICH
(Struthio camelus)

EXTERNAL FEATURES OF A BIRD





SKELETON OF A BIRD



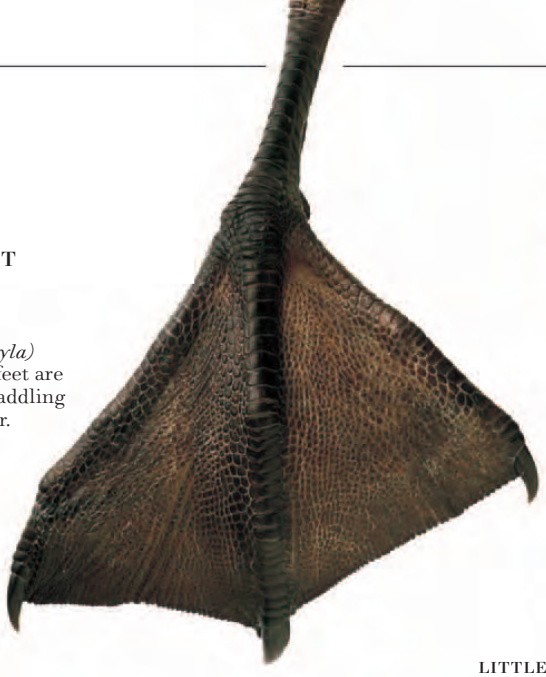
INTERNAL ANATOMY OF A BIRD

MALE KESTREL
(Falco tinnunculus)

COMMON BLACKHEADED GULL
(Larus ridibundus)

Birds 2

EXAMPLES OF BIRDS' FEET

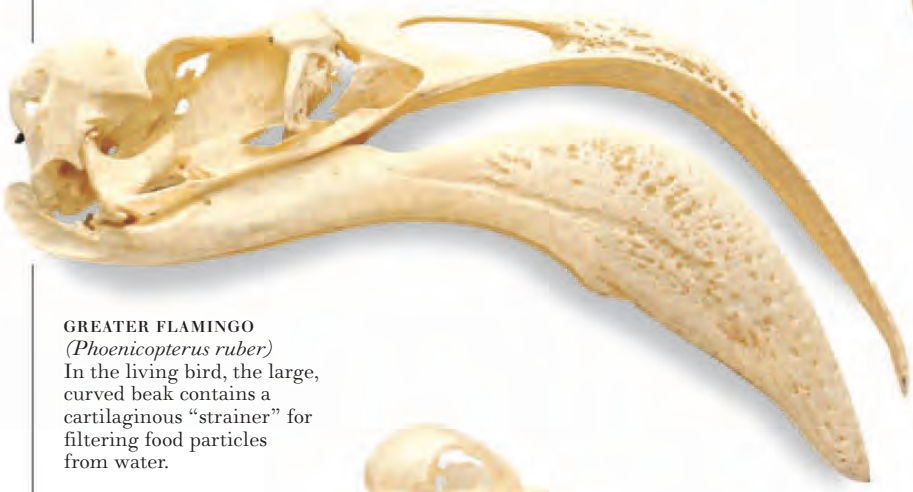


KITTIWAKE
(Rissa tridactyla)
The webbed feet are adapted for paddling through water.

TAWNY OWL
(Strix aluco)
The clawed feet are adapted for gripping prey.

LITTLE GREBE
(Tachybaptus ruficollis)
The lobed, flattened feet are adapted for swimming underwater.

EXAMPLES OF BIRDS' BEAKS

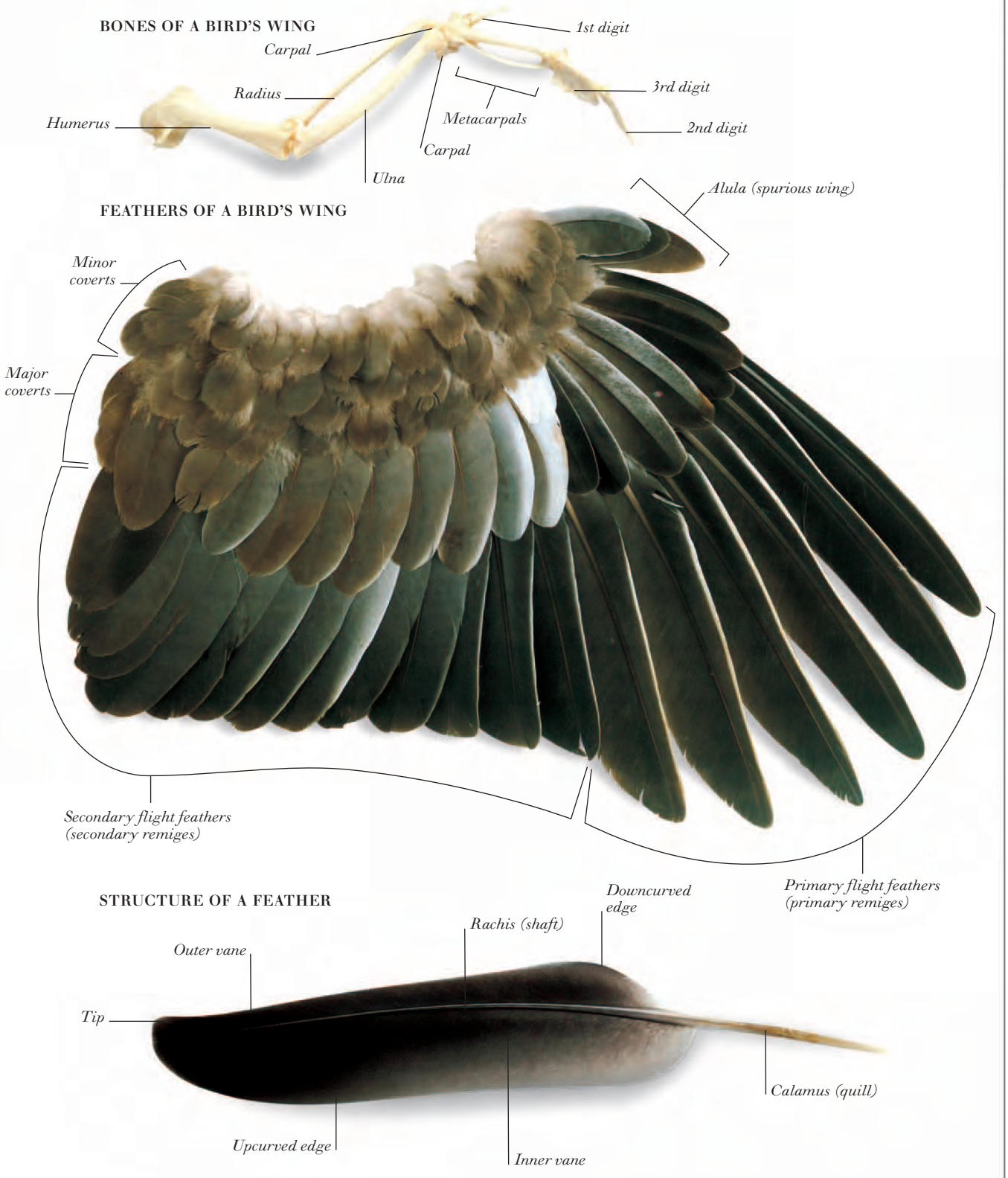


GREATER FLAMINGO
(Phoenicopterus ruber)
In the living bird, the large, curved beak contains a cartilaginous "strainer" for filtering food particles from water.

MISTLE THRUSH
(Turdus viscivorus)
The general-purpose beak is suitable for a wide range of animal and plant foods.

KING VULTURE
(Sarcorhamphus papa)
The hooked beak is adapted for pulling apart flesh.

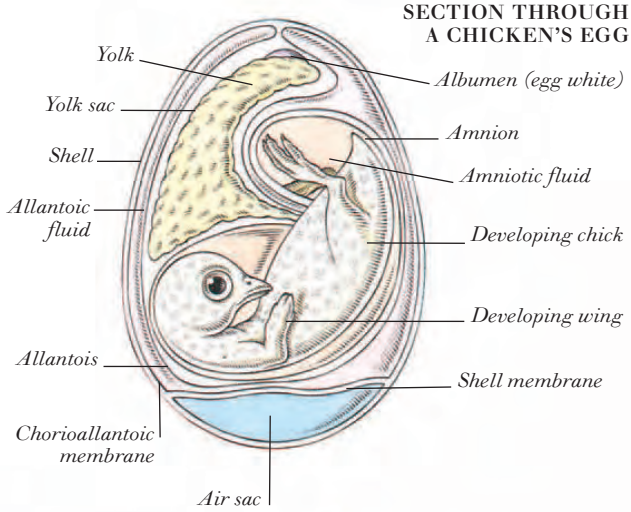
BLUE-AND-YELLOW MACAW
(Ara ararauna)
The broad, powerful, hooked beak is adapted for crushing seeds and eating fruit.


BONES OF A BIRD'S WING
1st digit
Carpal
Radius
3rd digit
Humerus
Metacarpals
2nd digit
Carpal
Ulna
FEATHERS OF A BIRD'S WING
Alula (spurious wing)
Minor coverts
Major coverts
Secondary flight feathers (secondary remiges)
Primary flight feathers (primary remiges)
STRUCTURE OF A FEATHER
Downcurved edge
Rachis (shaft)
Outer vane
Tip
Calamus (quill)
Upcurved edge
Inner vane

Eggs

AN EGG IS A SINGLE CELL, produced by the female, with the capacity to develop into a new individual. Development may take place inside the mother's body (as in most mammals) or outside, in which case the egg has a protective covering such as a shell. Egg yolk nourishes the growing young. Eggs developing inside the mother generally have little yolk, because the young are nourished from her body. Eggs developing outside may also have little yolk if they are produced by animals whose young go through a larval stage (such as a caterpillar) that feeds itself while developing into the adult form. The shelled eggs of birds and reptiles contain enough yolk to sustain the young until it hatches into a juvenile version of the adult.

SECTION THROUGH A CHICKEN'S EGG

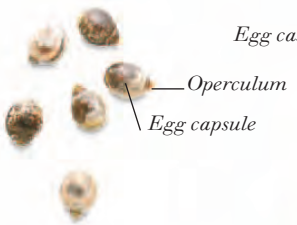


VARIETY OF EGGS

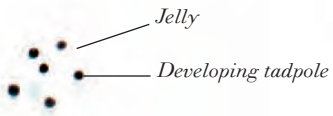
LEAF INSECT EGGS

GIANT STICK INSECT EGGS

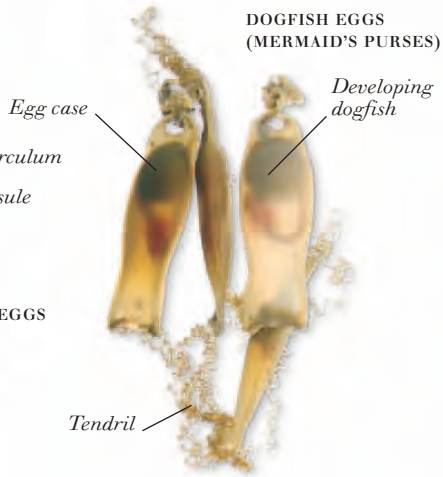
INDIAN STICK INSECT EGGS



FROG EGGS (FROG SPAWN)

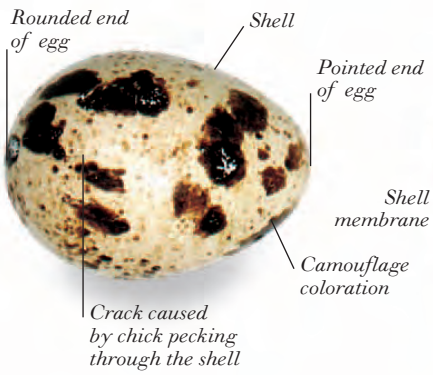


DOGFISH EGGS (MERMAID'S PURSES)

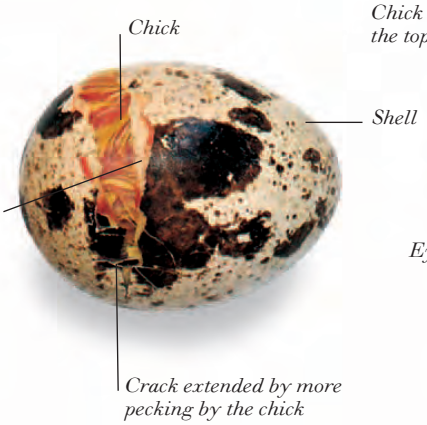


HATCHING OF A QUAIL'S EGG

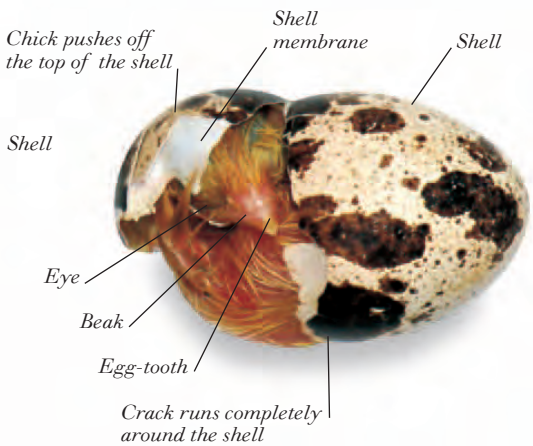
EGG AT THE POINT OF HATCHING



CUTTING THROUGH THE EGG



BREAKING OUT OF THE EGG



EXAMPLES OF BIRDS' EGGS

GREATER BLACKBACKED GULL
(Larus marinus)

BEE HUMMINGBIRD
(Calypte helenae)

BALTIMORE ORIOLE
(Icterus galbula)

WILLOW GROUSE
(Lagopus lagopus)

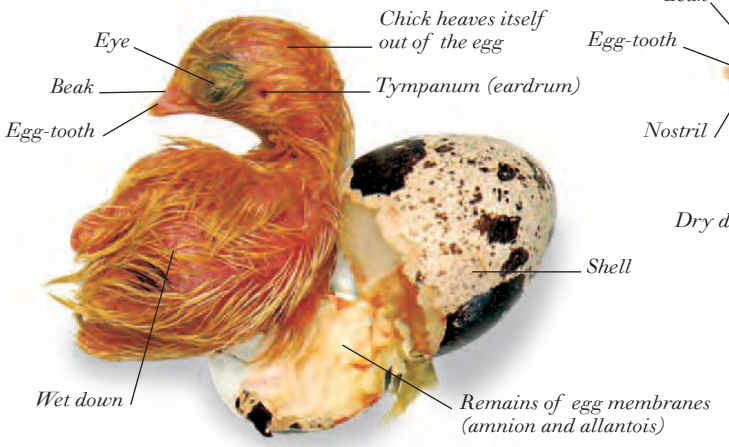
COMMON TERN
(Sterna hirundo)

CARRION CROW
(Corvus corone)

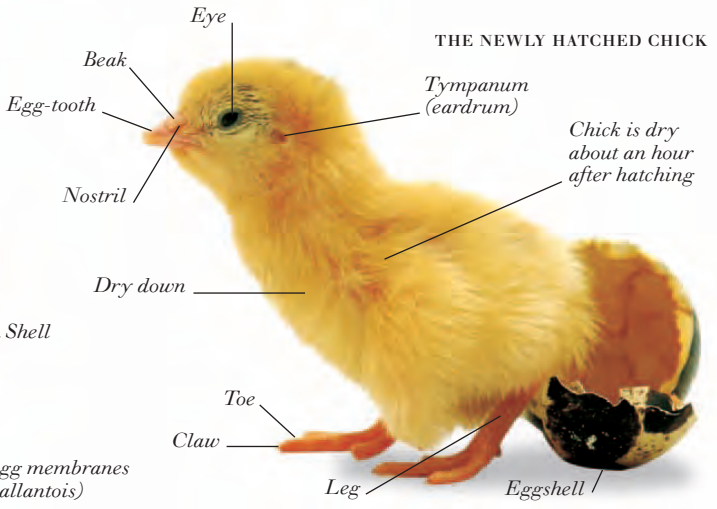
CHAFFINCH
(Fringilla coelebs)

OSTRICH
(Struthio camelus)

EMERGING FROM THE EGG



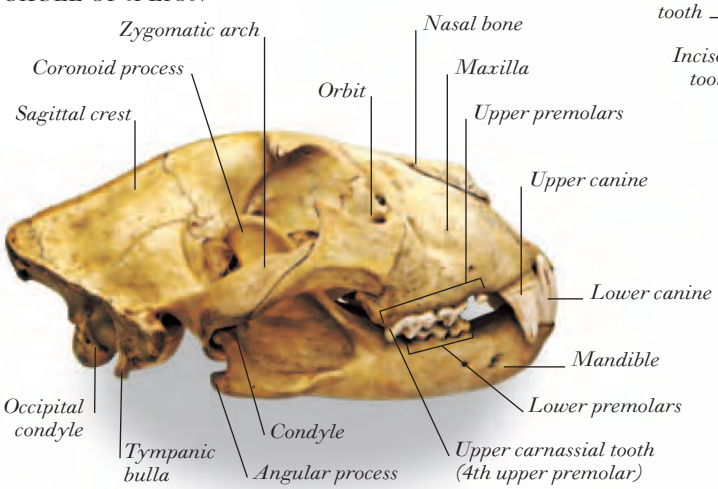
THE NEWLY HATCHED CHICK



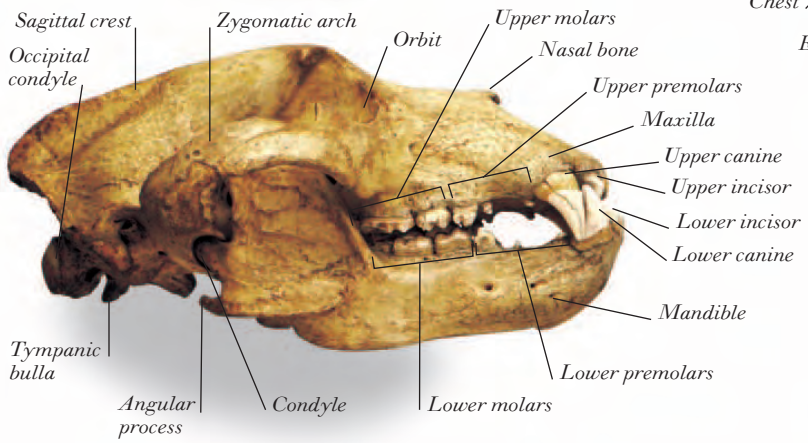
Carnivores

THE MAMMALIAN ORDER CARNIVORA includes cats, dogs, bears, raccoons, pandas, weasels, badgers, skunks, otters, civets, mongooses, and hyenas. The order's name is derived from the fact that most of its members are carnivores (flesh-eaters). Typical carnivore features therefore reflect a hunting life-style: speed and agility; sharp claws and well-developed canine teeth for holding and killing prey; carnassial teeth (cheek teeth) for cutting flesh; and forward-facing eyes for good distance judgment. However, some members of the order—bears, badgers, and foxes, for example—have a more mixed diet, and a few are entirely herbivorous (plant-eating), notably pandas. Such animals have no carnassial teeth and tend to be slower moving than pure flesh-eaters.

SKULL OF A LION



SKULL OF A BEAR



EXTERNAL FEATURES OF A MALE LION

EXAMPLES OF CARNIVORES

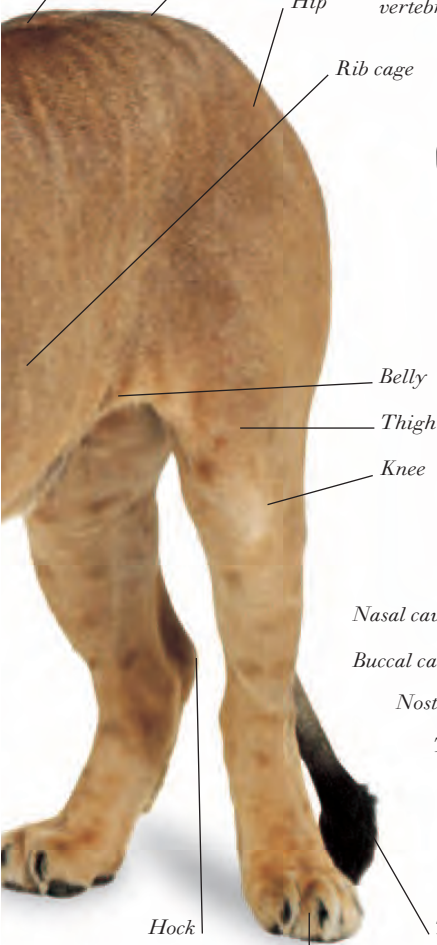
ALSATIAN DOG
(Canis familiaris)

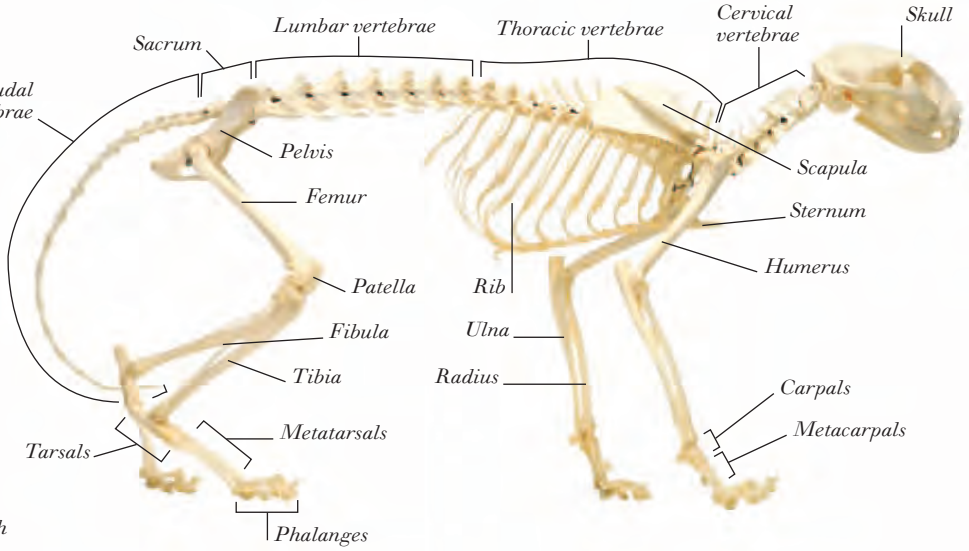
MANED WOLF
(Chrysocyon brachyurus)

RACCOON
(Procyon lotor)

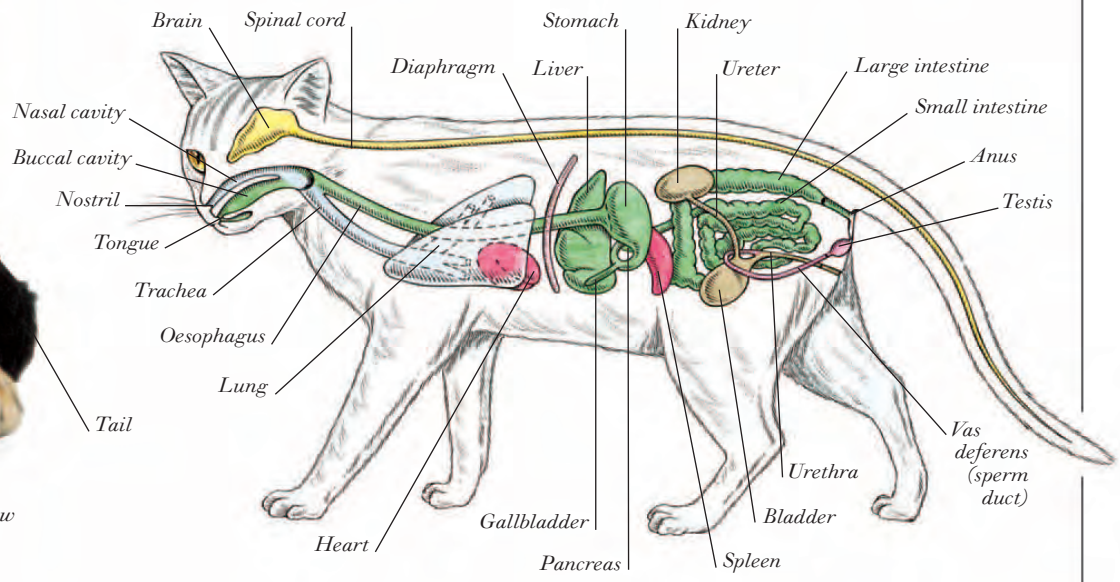
AMERICAN BLACK BEAR
(Ursus americanus)

SKELETON OF A DOMESTIC CAT





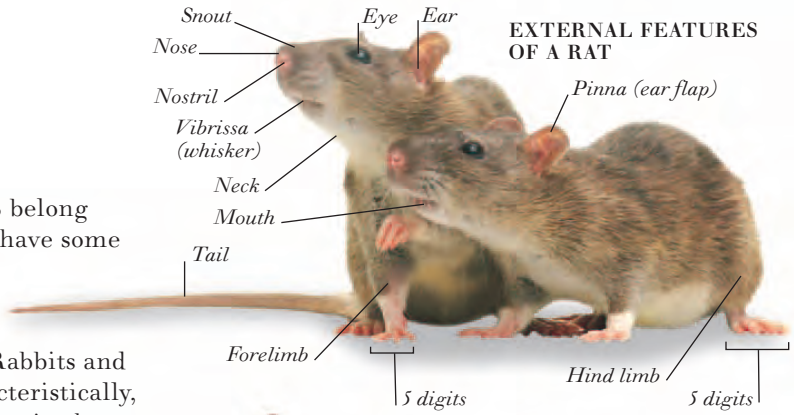
INTERNAL ANATOMY OF A MALE DOMESTIC CAT



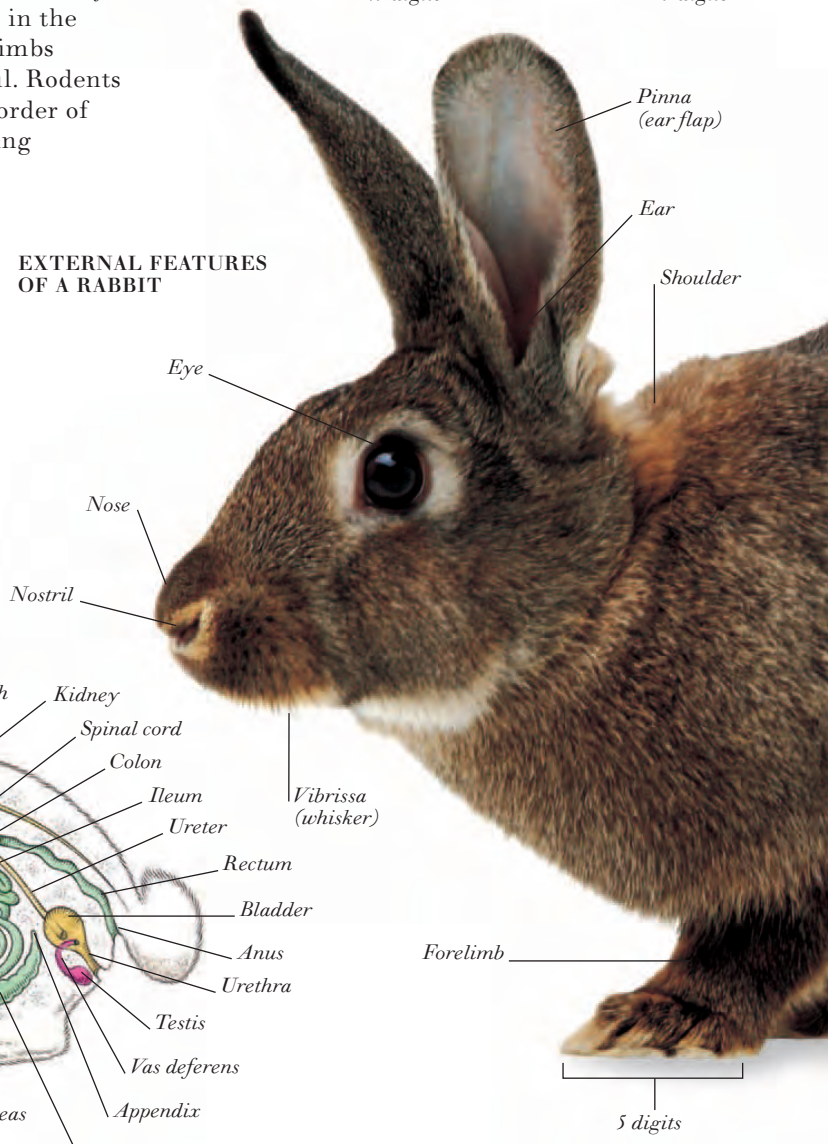
Rabbits and rodents

ALTHOUGH RABBITS AND RODENTS belong to different orders of mammals, they have some features in common. These features include chisel-shaped incisor teeth that grow continually, and eating their feces to extract more nutrients from their plant diet. Rabbits and hares belong to the order Lagomorpha. Characteristically, they have four incisors in the upper jaw and two in the lower jaw; powerful hind legs for jumping; forelimbs adapted for burrowing; long ears; and a small tail. Rodents make up the order Rodentia. This is the largest order of mammals, with more than 1,700 species, including squirrels, beavers, chipmunks, gophers, rats, mice, lemmings, gerbils, porcupines, cavies, and the capybara. Typical rodent features include two incisors in each jaw; short forelimbs for manipulating food; and cheek pouches for storing food.

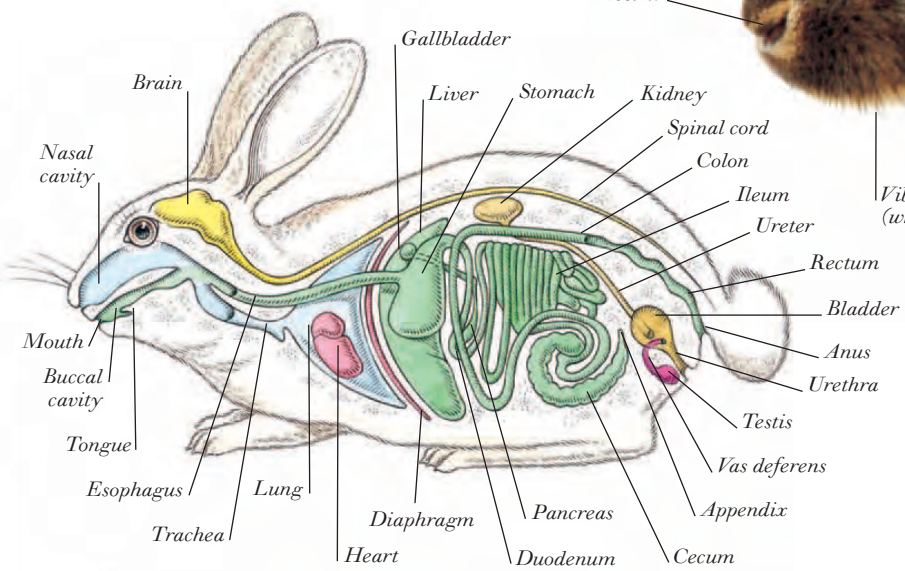
EXTERNAL FEATURES OF A RAT



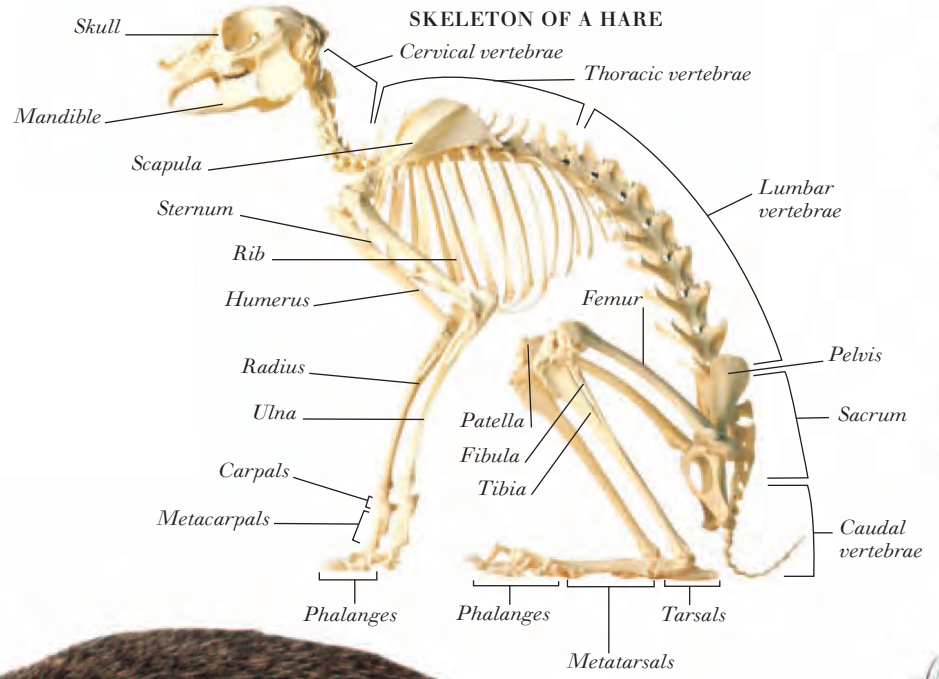
EXTERNAL FEATURES OF A RABBIT

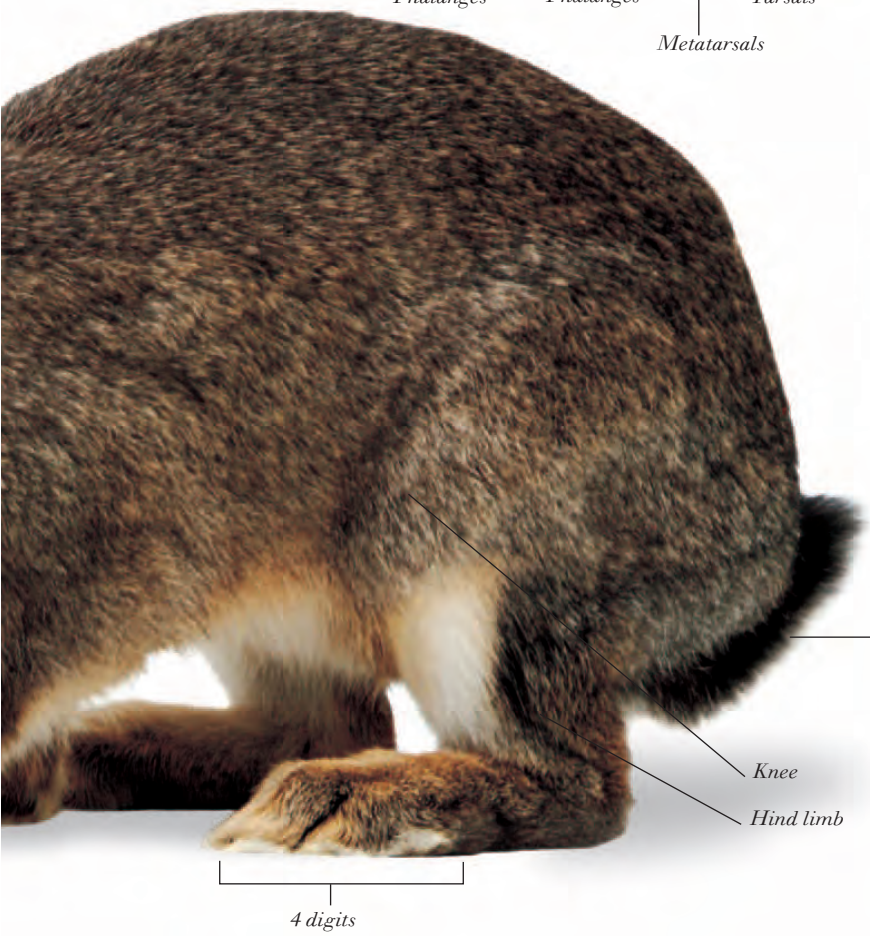


INTERNAL ANATOMY OF A MALE RABBIT



SKELETON OF A HARE





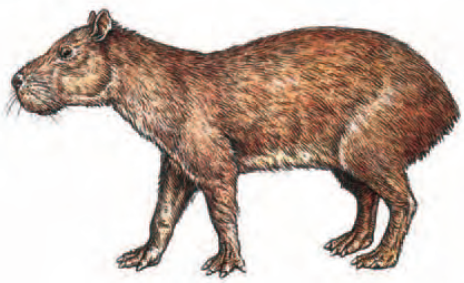
EXAMPLES OF RODENTS

GRAY SQUIRREL
(Sciuris carolinensis)

PLAINS VISCACHA
(Lagostomus maximus)

CRESTED PORCUPINE
(Hystrix africaeaustralis)

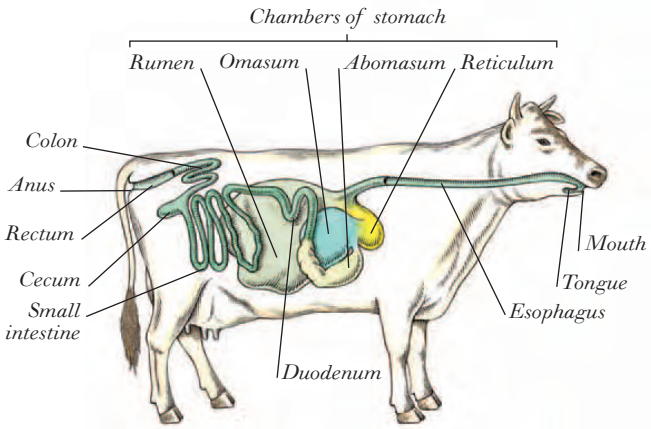
AMERICAN BEAVER
(Castor canadensis)



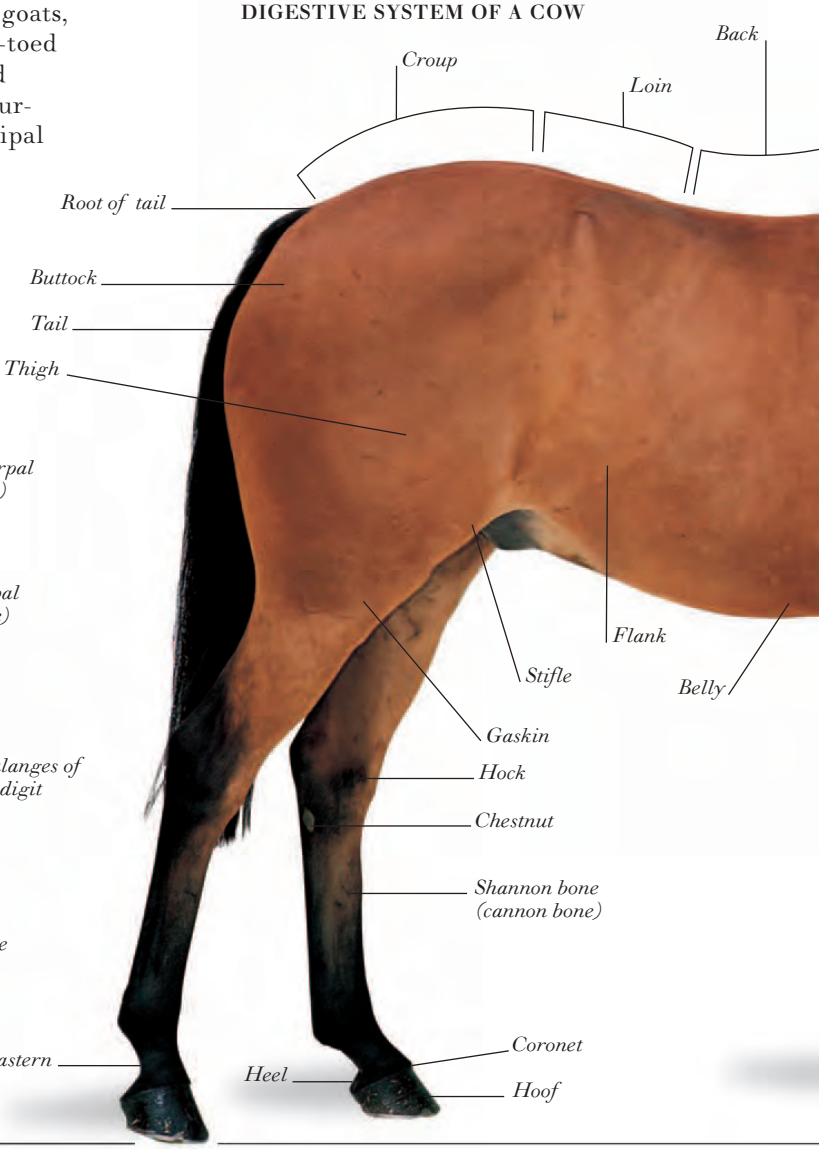
CAPYBARA
(Hydrochoerus hydrochaeris)

Ungulates

UNGULATES IS A GENERAL TERM FOR a large, varied group of mammals that includes horses, cattle, and their relatives. The ungulates are divided into two orders on the basis of the number of toes. Members of the order Perissodactyla (odd-toed ungulates) have one or three toes. Perissodactyls include horses, onagers, and zebras (all of which are one-toed), and rhinoceroses and tapirs (which are three-toed). Members of the order Artiodactyla (even-toed ungulates) have two or four toes. Most artiodactyls have two toes, which are typically encased in hooves to give the so-called cloven hoof. Two-toed, cloven-hoofed artiodactyls include cows and other cattle, sheep, goats, antelopes, deer, and giraffes. The other main two-toed artiodactyls are camels and llamas. Most two-toed artiodactyls are ruminants; that is, they have a four-chambered stomach and chew the cud. The principal four-toed artiodactyls are pigs, peccaries, and hippopotamuses.



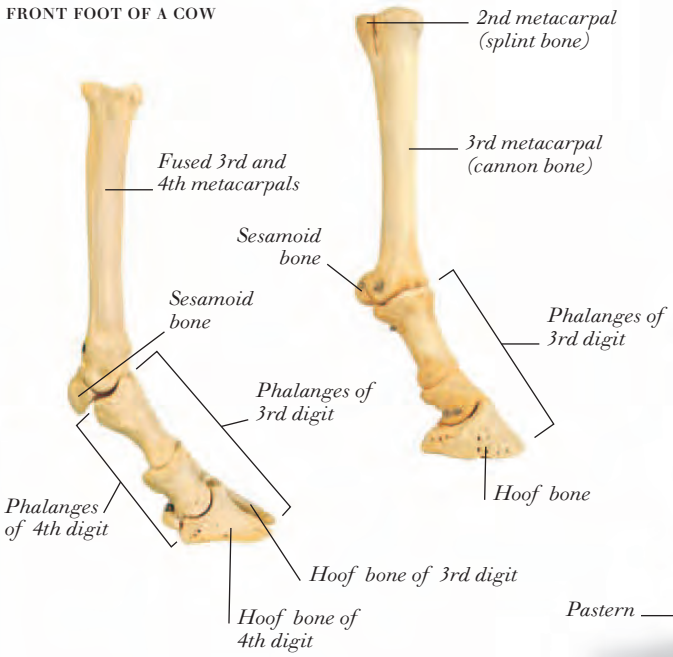
DIGESTIVE SYSTEM OF A COW



COMPARISON OF THE FRONT FEET OF A HORSE AND A COW

SKELETON OF THE LEFT FRONT FOOT OF A HORSE

SKELETON OF THE RIGHT FRONT FOOT OF A COW



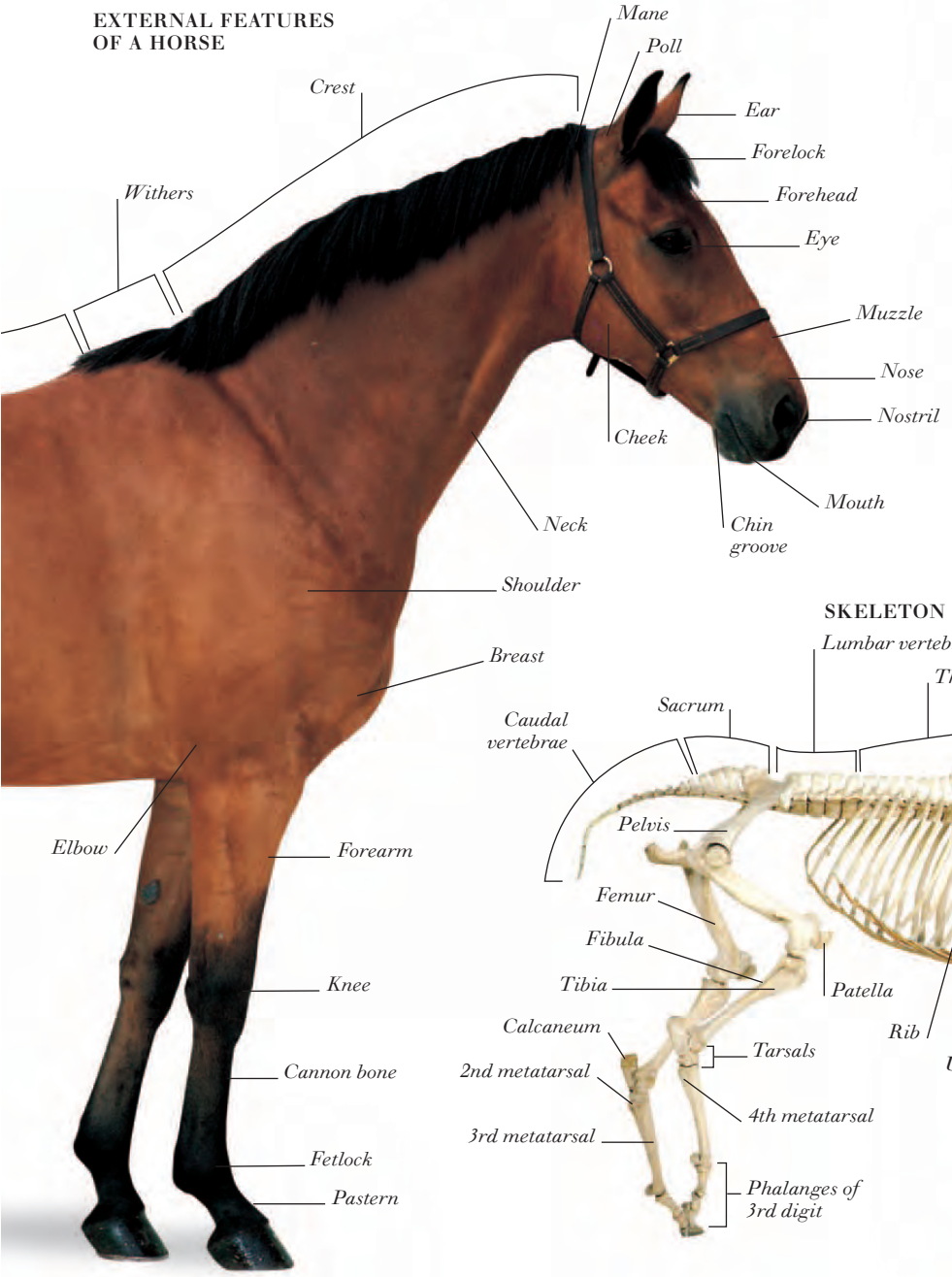
EXAMPLES OF UNGULATES

MALE RED DEER
(Cervus elephas)
An even-toed ungulate
(order Artiodactyla)

BACTRIAN CAMEL
(Camelus ferus)
An even-toed ungulate
(order Artiodactyla)

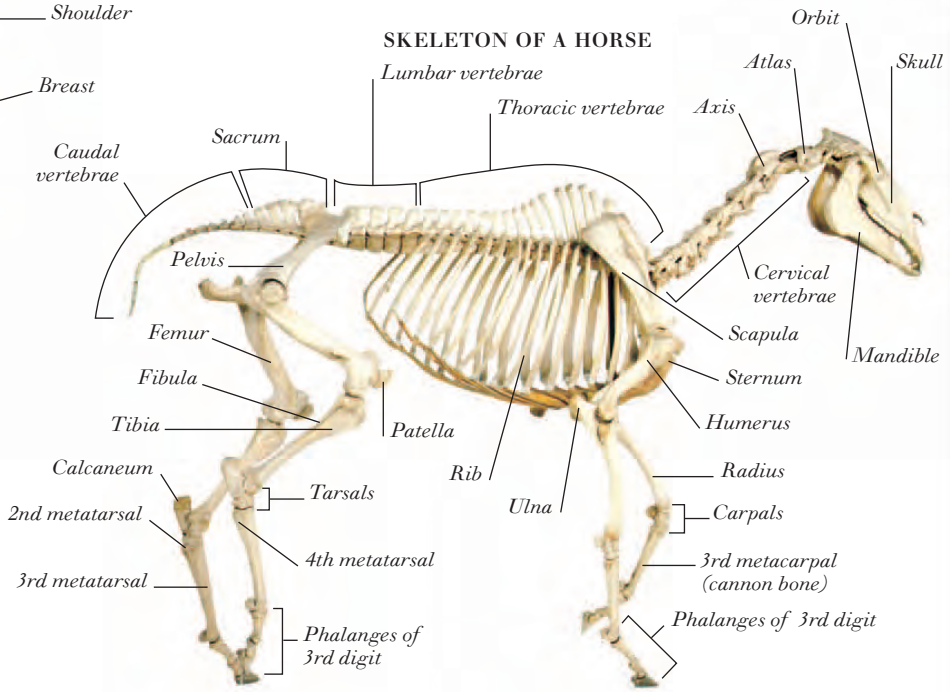
GIRAFFE
(Giraffa camelopardalis)
An even-toed ungulate
(order Artiodactyla)

EXTERNAL FEATURES OF A HORSE



BLACK RHINOCEROS
(Diceros bicornis)
An odd-toed ungulate
(order Perissodactyla)

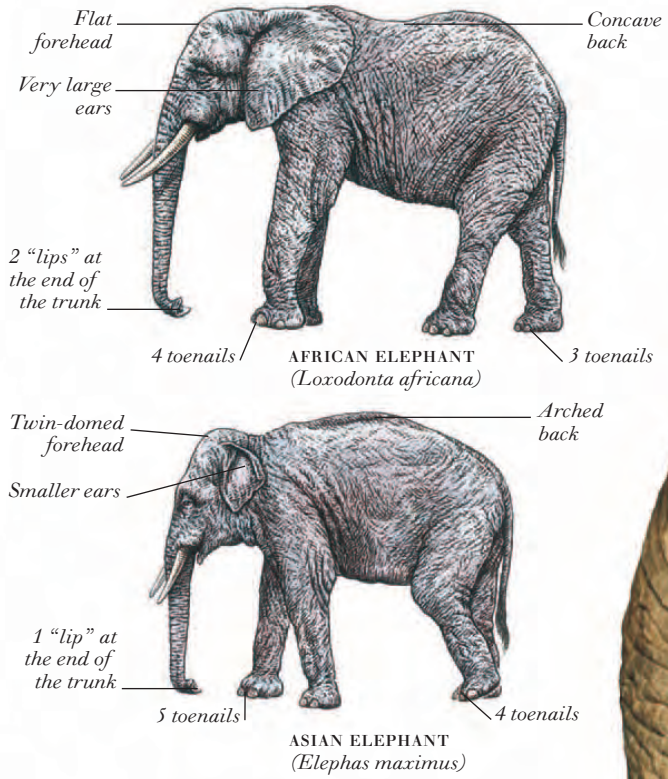
SKELETON OF A HORSE



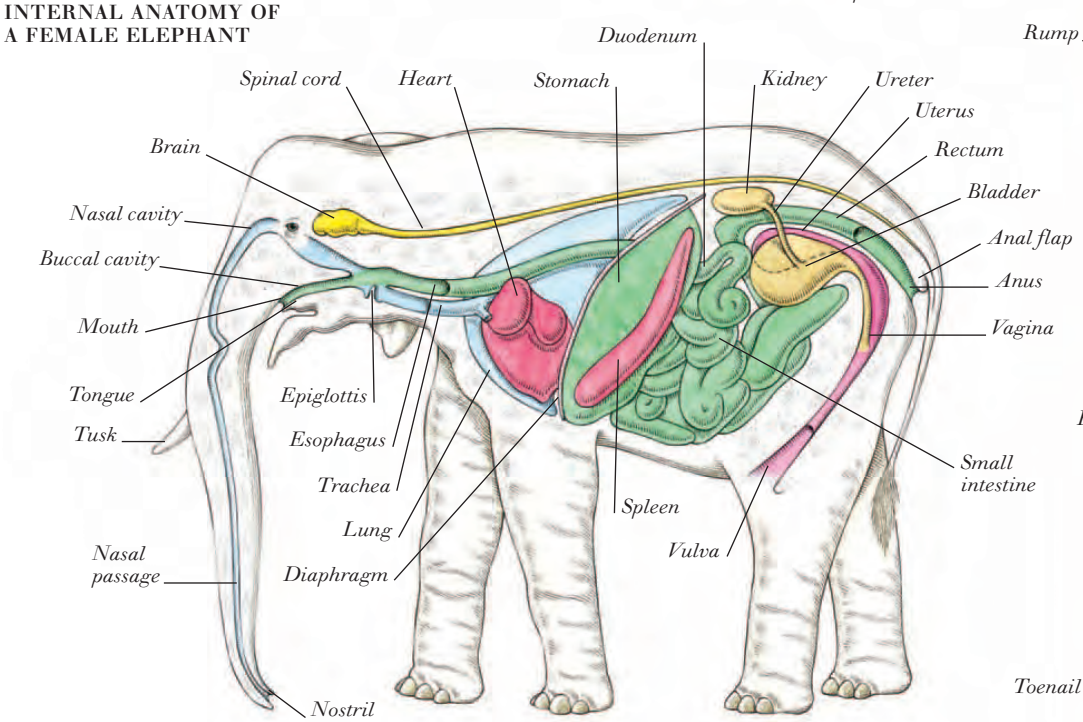
Elephants

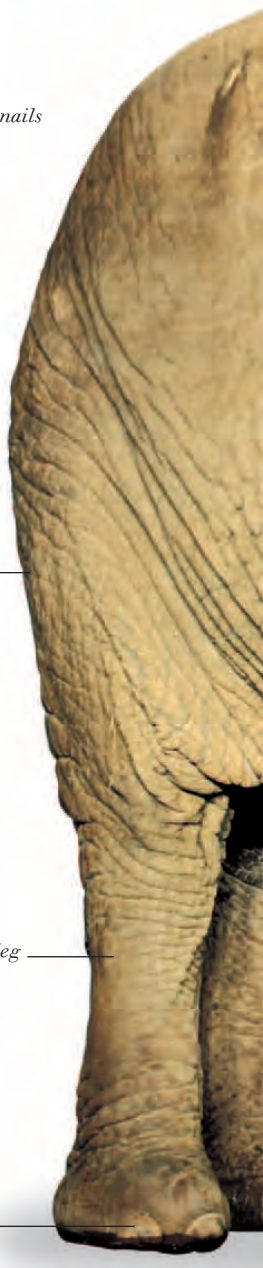
THE TWO SPECIES OF elephant—African and Asian—are the only members of the mammalian order Proboscidea. The bigger African elephant is the largest land animal: a fully grown male may be up to 13 ft (4 m) tall and weigh nearly 8 tons (7 metric tons). A fully grown male Asian elephant may be 11 ft (3.3 m) tall and weigh 6 tons (5.4 metric tons). The trunk—an extension of the nose and upper lip—is the elephant's other most obvious feature. It is used for manipulating and lifting, feeding, drinking and spraying water, smelling, touching, and producing trumpeting sounds. Other characteristic features include a pair of tusks, used for defense and for crushing vegetation; thick, pillarlike legs and broad feet to support the massive body; and large ear flaps that act as radiators to keep the elephant cool.

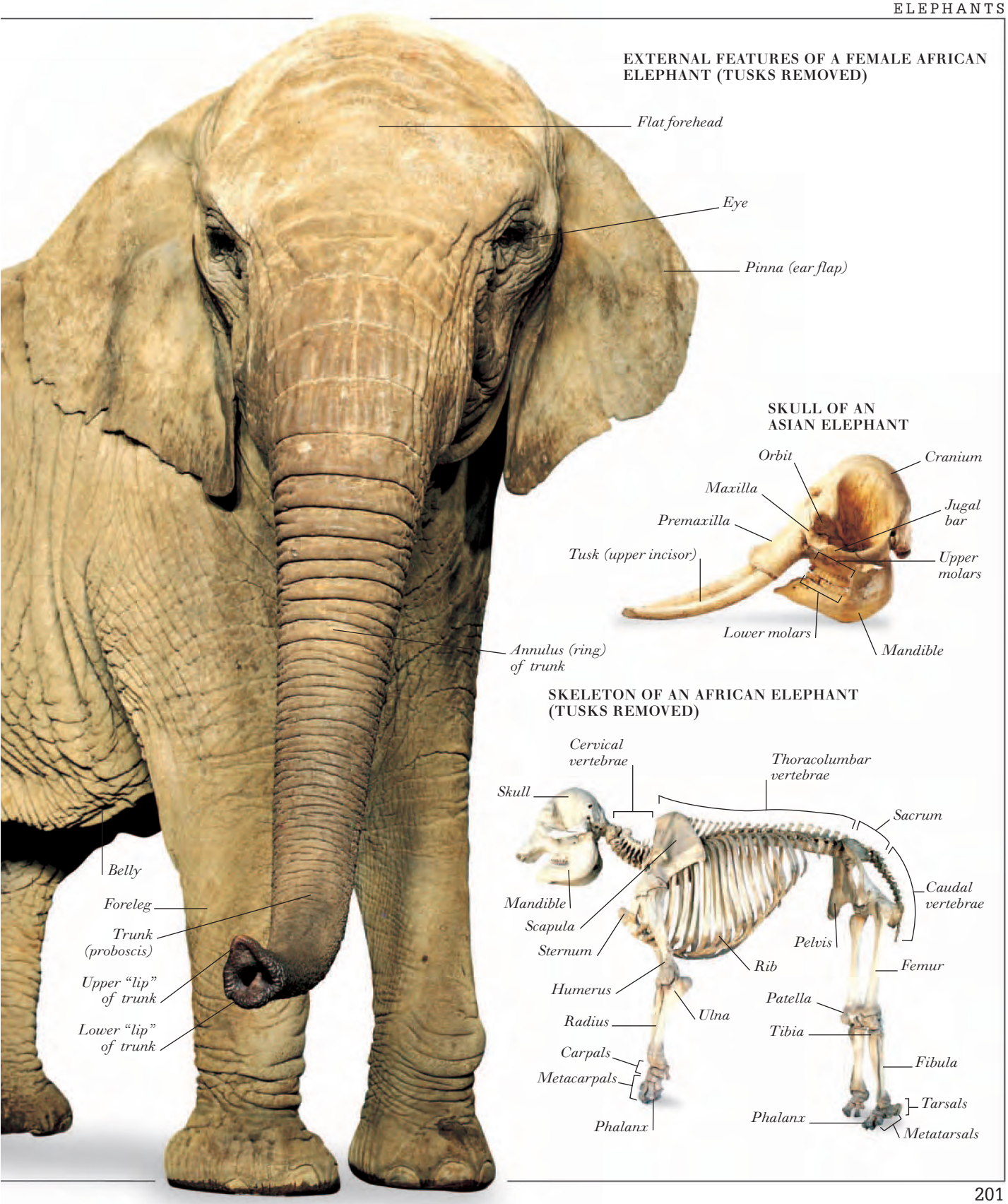
DIFFERENCES BETWEEN AFRICAN AND ASIAN ELEPHANTS



INTERNAL ANATOMY OF A FEMALE ELEPHANT



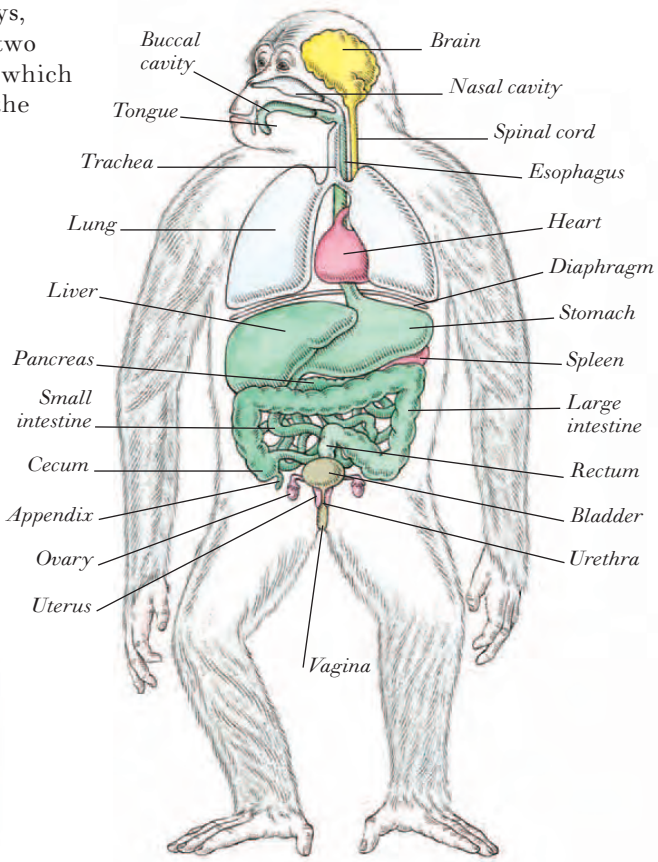



EXTERNAL FEATURES OF A FEMALE AFRICAN ELEPHANT (TUSKS REMOVED)
Flat forehead
Eye
Pinna (ear flap)
Annulus (ring) of trunk
Belly
Foreleg
Trunk (proboscis)
Upper "lip" of trunk
Lower "lip" of trunk
SKULL OF AN ASIAN ELEPHANT
Orbit
Cranium
Maxilla
Jugal bar
Premaxilla
Tusk (upper incisor)
Upper molars
Lower molars
Mandible
SKELETON OF AN AFRICAN ELEPHANT (TUSKS REMOVED)
Cervical vertebrae
Thoracolumbar vertebrae
Skull
Sacrum
Caudal vertebrae
Mandible
Scapula
Sternum
Pelvis
Rib
Femur
Humerus
Ulna
Patella
Radius
Tibia
Carpals
Fibula
Metacarpals
Tarsals
Phalanx
Phalanx
Metatarsals

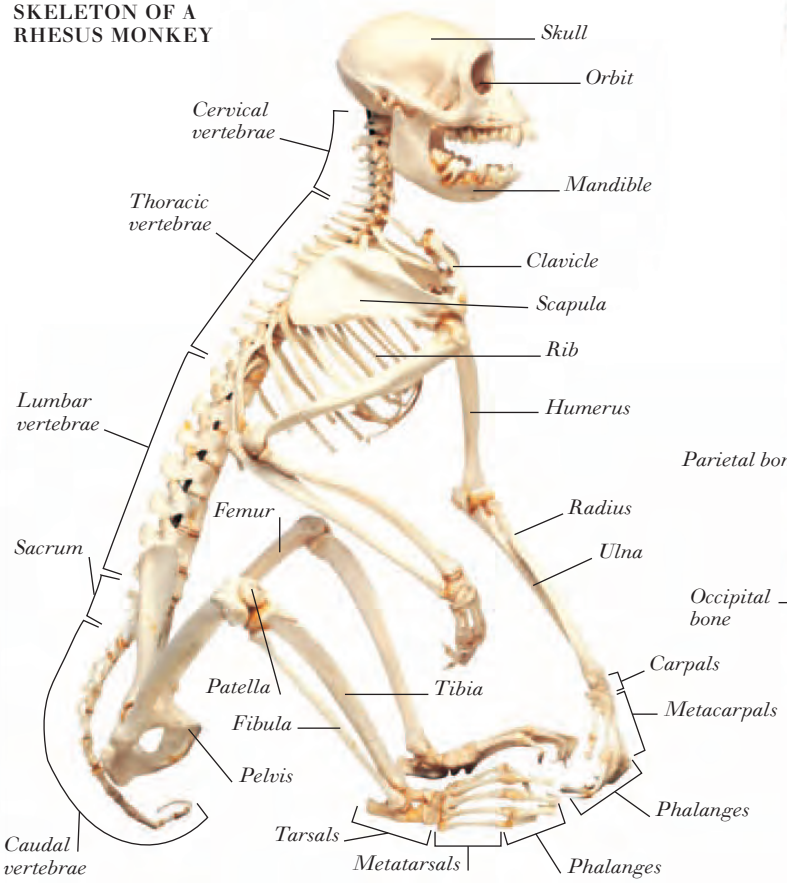
Primates

THE MAMMALIAN ORDER PRIMATES consists of monkeys, apes, and their relatives (including humans). There are two suborders of primates: Prosimii, the primitive primates, which include lemurs, tarsiers, and lorises; and Anthropoidea, the advanced primates, which include monkeys, apes, and humans. The anthropoids are divided into New World monkeys, Old World monkeys, and hominids. New World monkeys typically have wide-apart nostrils that open to the side; and long tails, which are prehensile (grasping) in some species. This group of monkeys lives in South America, and includes marmosets, tamarins, and howler monkeys. Old World monkeys typically have close-set nostrils that open forward or downward; and non-prehensile tails. This group of monkeys lives in Africa and Asia, and includes langurs, mandrills, macaques, and baboons. Hominids typically have large brains, and no tail. This group includes the apes—chimpanzees, gibbons, gorillas, and orangutans—and humans.

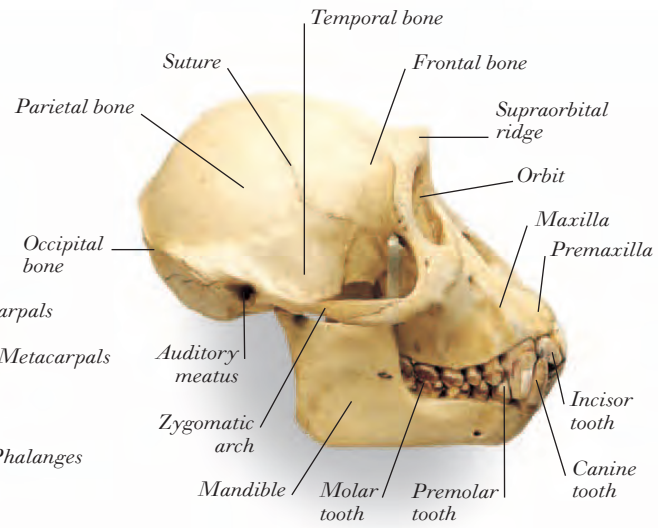
INTERNAL ANATOMY OF A FEMALE CHIMPANZEE



SKELETON OF A RHESUS MONKEY



SKULL OF A CHIMPANZEE



EXAMPLES OF PRIMATES

RING-TAILED LEMUR
(Lemur catta)
A prosimian

MALE RED HOWLER MONKEY
(Alouatta seniculus)
A New World monkey

MALE MANDRILL
(Mandrillus sphinx)
An Old World monkey

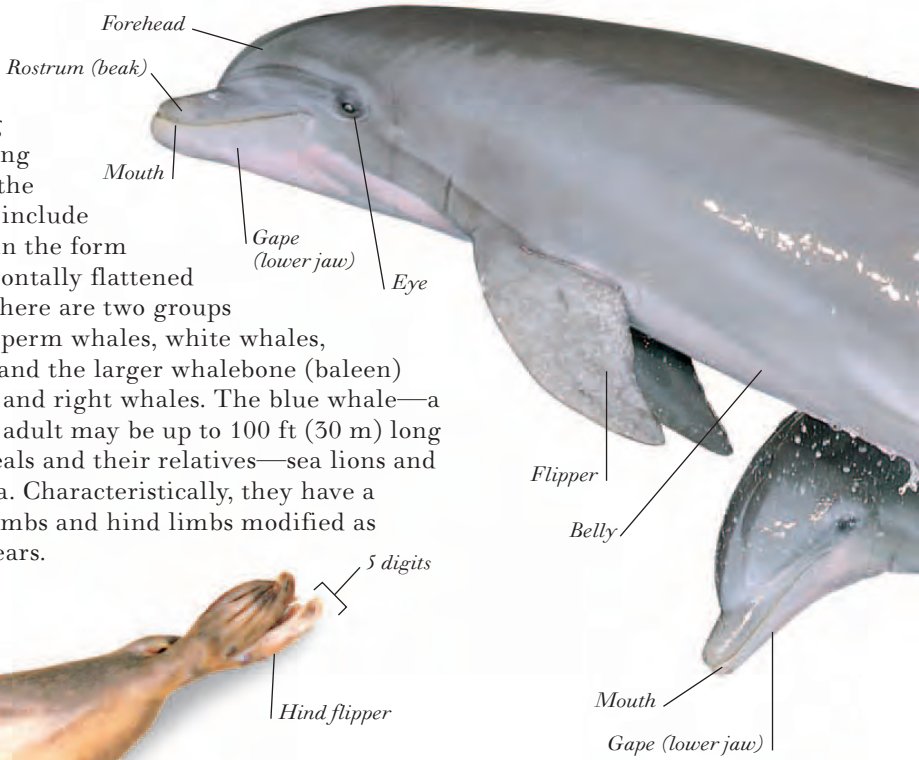
CHIMPANZEE
(Pan troglodytes)
An ape

EXTERNAL FEATURES OF A YOUNG GORILLA

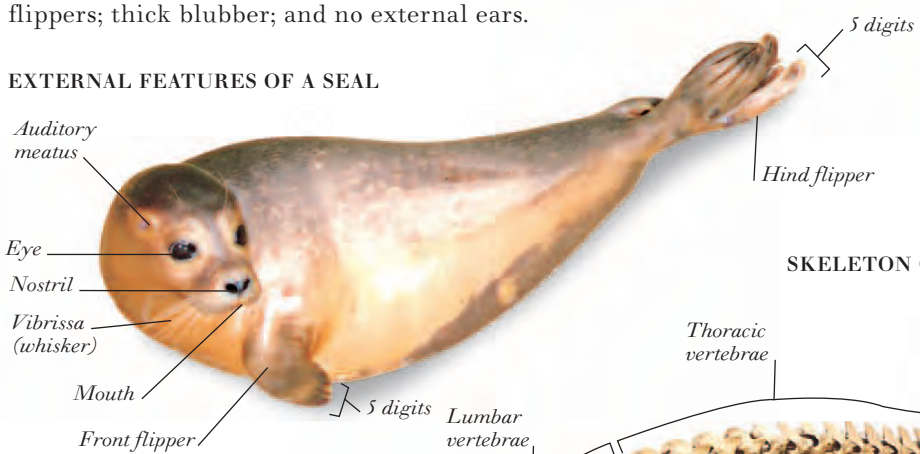
GOLDEN LION TAMARIN
(Leontopithecus rosalia)
A New World monkey

Dolphins, whales, and seals

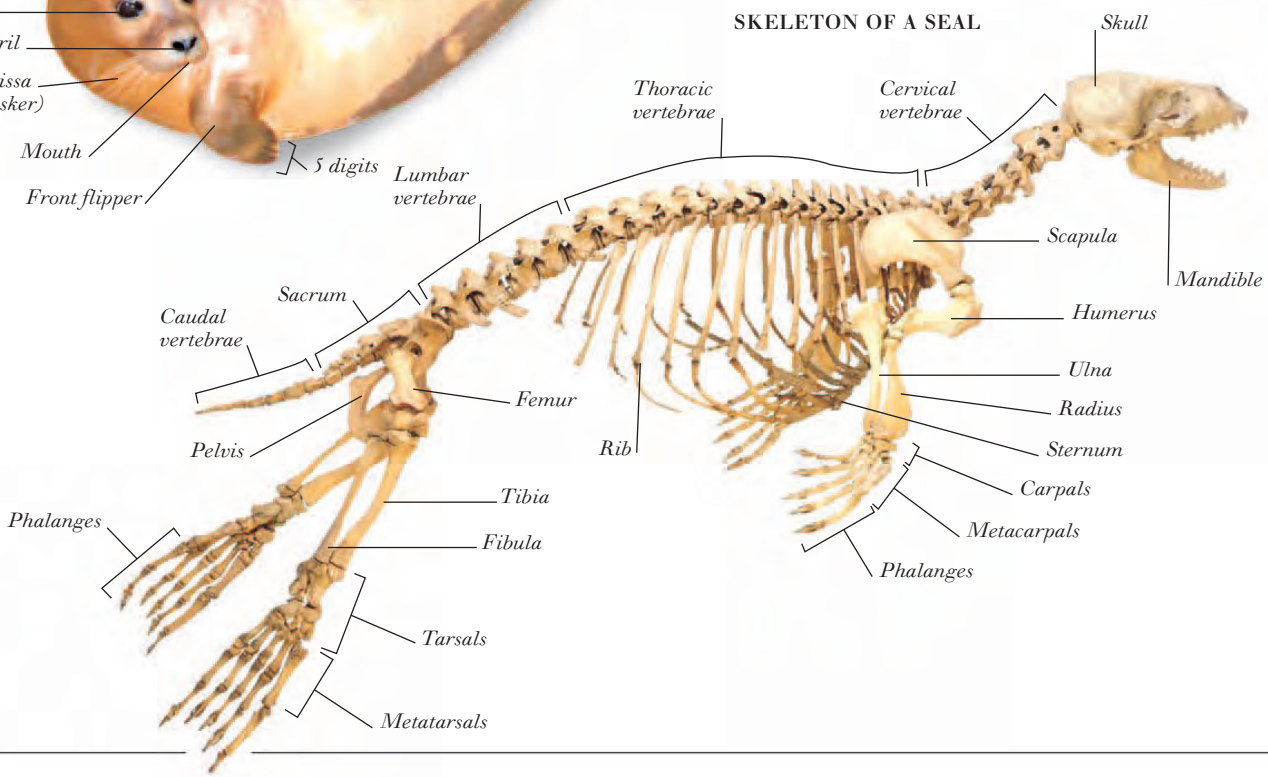
DOLPHINS, WHALES, AND SEALS belong to two orders of mammal adapted to living in water. Dolphins and whales make up the order Cetacea. Typical cetacean features include a streamlined, fishlike shape; forelimbs in the form of flippers; no visible hind limbs; a horizontally flattened tail; and thick blubber under the skin. There are two groups of cetaceans: toothed whales, including sperm whales, white whales, beaked whales, dolphins, and porpoises; and the larger whalebone (baleen) whales, including rorquals, gray whales, and right whales. The blue whale—a rorqual—is the largest living animal: an adult may be up to 100 ft (30 m) long and weigh 145 tons (130 metric tons). Seals and their relatives—sea lions and walruses—make up the order Pinnipedia. Characteristically, they have a streamlined, torpedo-shaped body; forelimbs and hind limbs modified as flippers; thick blubber; and no external ears.



EXTERNAL FEATURES OF A SEAL

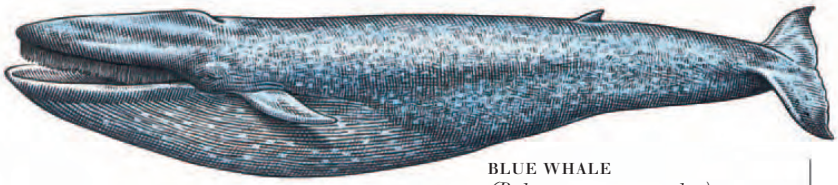


SKELETON OF A SEAL

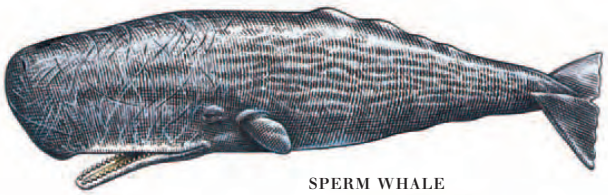


EXTERNAL FEATURES OF A DOLPHIN

EXAMPLES OF CETACEANS

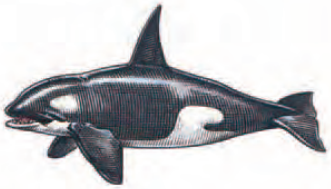


BLUE WHALE
(Balaenoptera musculus)



SPERM WHALE
(Physeter catodon)

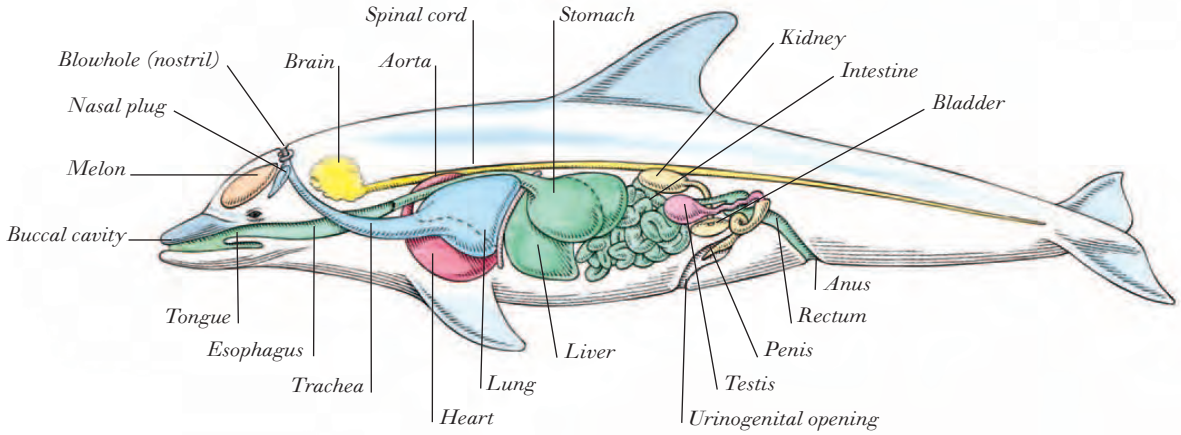
MALE BAIRD'S BEAKED WHALE
(Berardius bairdi)



MALE KILLER WHALE
(Orcinus orca)

MALE NARWHAL
(Monodon monoceros)

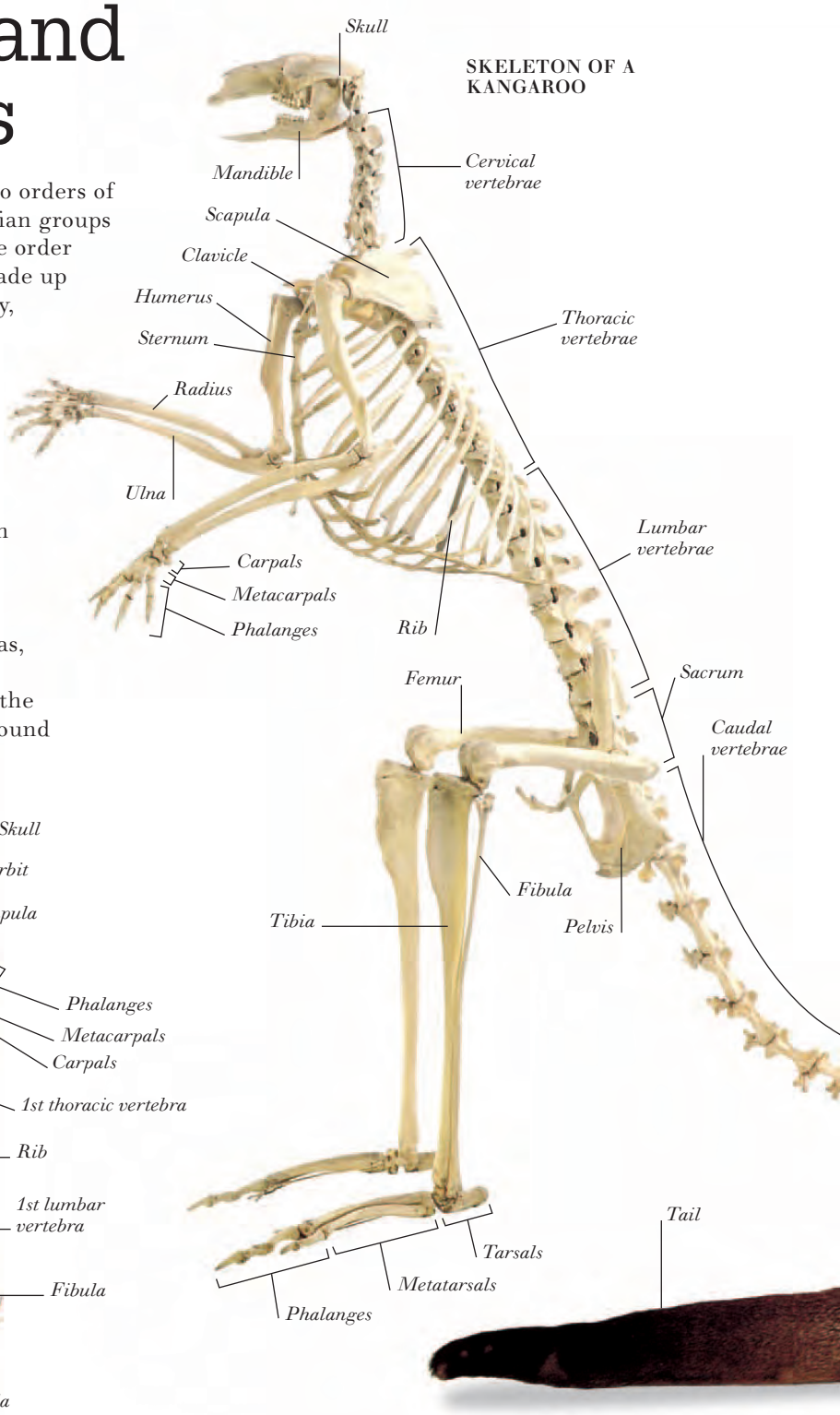
INTERNAL ANATOMY OF A MALE DOLPHIN



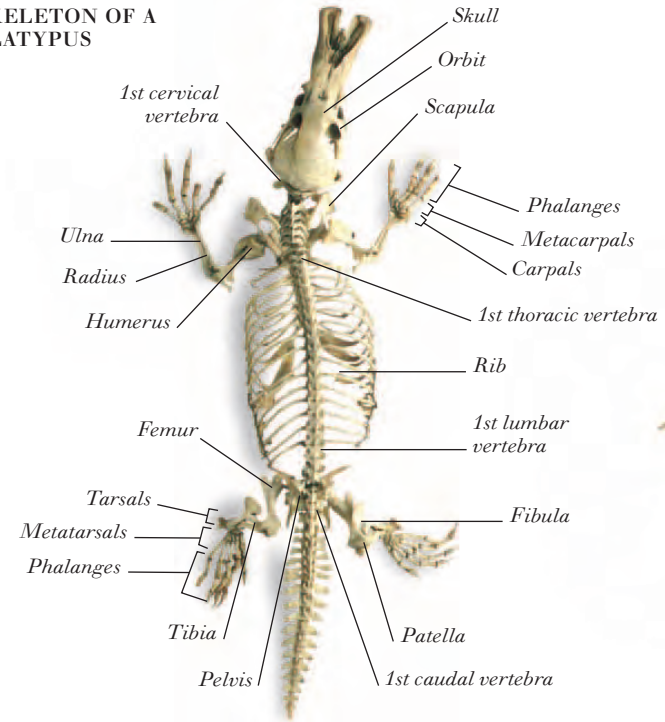
Marsupials and Monotremes

MARSUPIALS AND MONOTREMES are two orders of mammal that differ from other mammalian groups in the ways that their young develop. The order Marsupalia, the pouched mammals, is made up of kangaroos and their relatives. Typically, marsupials give birth to their young at a very early stage of development. The young then crawls to the mother's pouch (which is on the outside of her abdomen), where it attaches itself to a nipple and remains until fully developed. Most marsupials live in Australia, although the opossums—which are classified as marsupials despite not having a pouch—live in the Americas. The order Monotremata is made up of the platypus and its relatives (the echidnas, or spiny anteaters). The monotremes are primitive mammals that lay eggs, which the mother incubates. The monotremes are found only in Australia and New Guinea.

SKELETON OF A KANGAROO



SKELETON OF A PLATYPUS



EXAMPLES OF MARSUPIALS AND MONOTREMES

KOALA
(Phascolarctos cinereus)
A marsupial

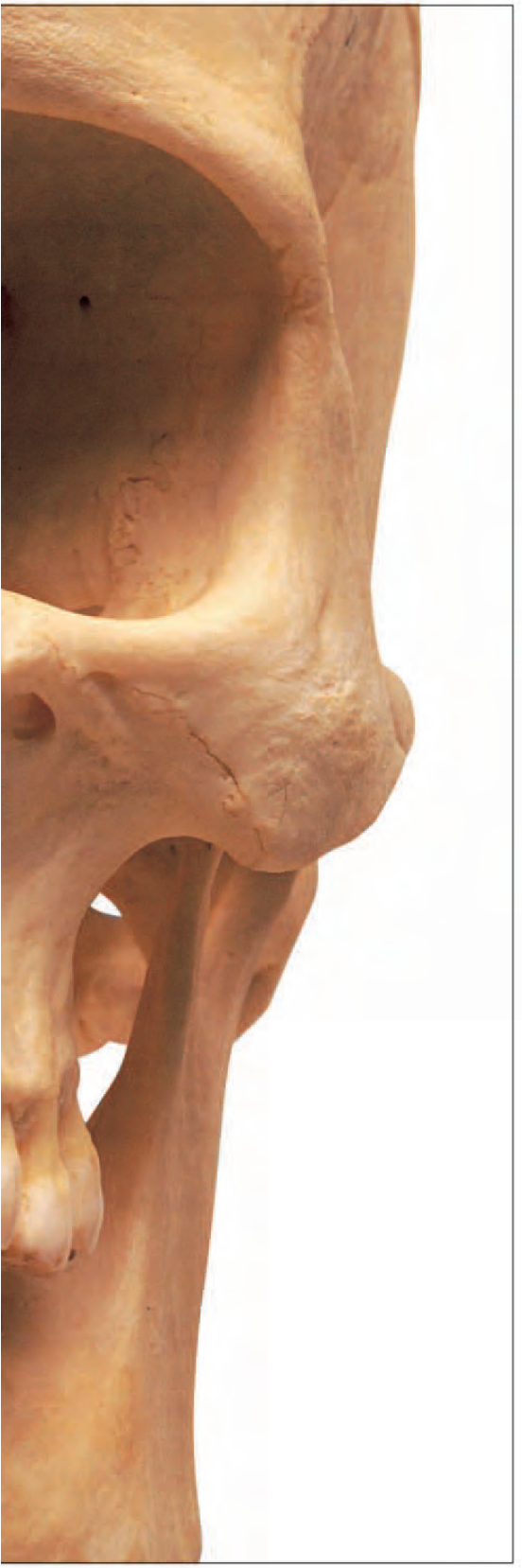
DUCK-BILLED PLATYPUS
(Ornithorhynchus anatinus)
A monotreme

TASMANIAN DEVIL
(Sarcophilus harrisii)
A marsupial

VIRGINIA OPOSSUM
(Didelphis virginiana)
A marsupial

EXTERNAL FEATURES OF A KANGAROO

Pinna (ear flap)
Ear
Eye
Nostril
Mouth
Forelimb
Knee
Thigh
Hip
Claw
5 digits
3 digits
Hind limb
Lower leg
Hip
Claw
Foot



The Human Body

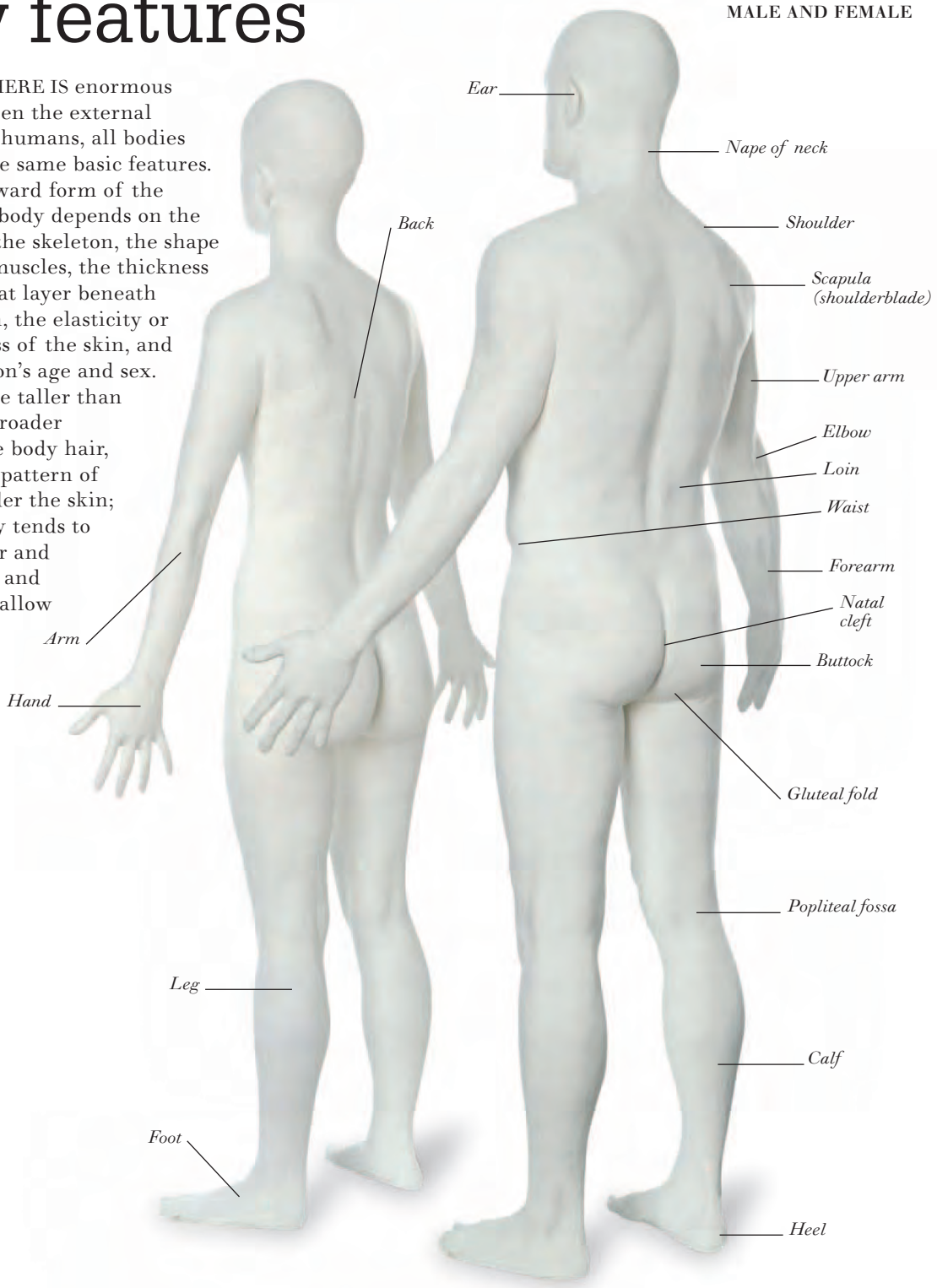
Body Features 210
Head 212
Body Organs 214
Body Cells 216
Skeleton 218
Skull 220
Spine 222
Bones and Joints 224
Muscles 1 226
Muscles 2 228
Hands 230
Feet 232
Skin and Hair 234
Brain 236
Nervous System 238
Eye 240
Ear 242
Nose, Mouth, and Throat 244
Teeth 246
Digestive System 248
Heart 250
Circulatory System 252
Respiratory System 254
Urinary System 256
Reproductive System 258
Development of a Baby 260

Body features

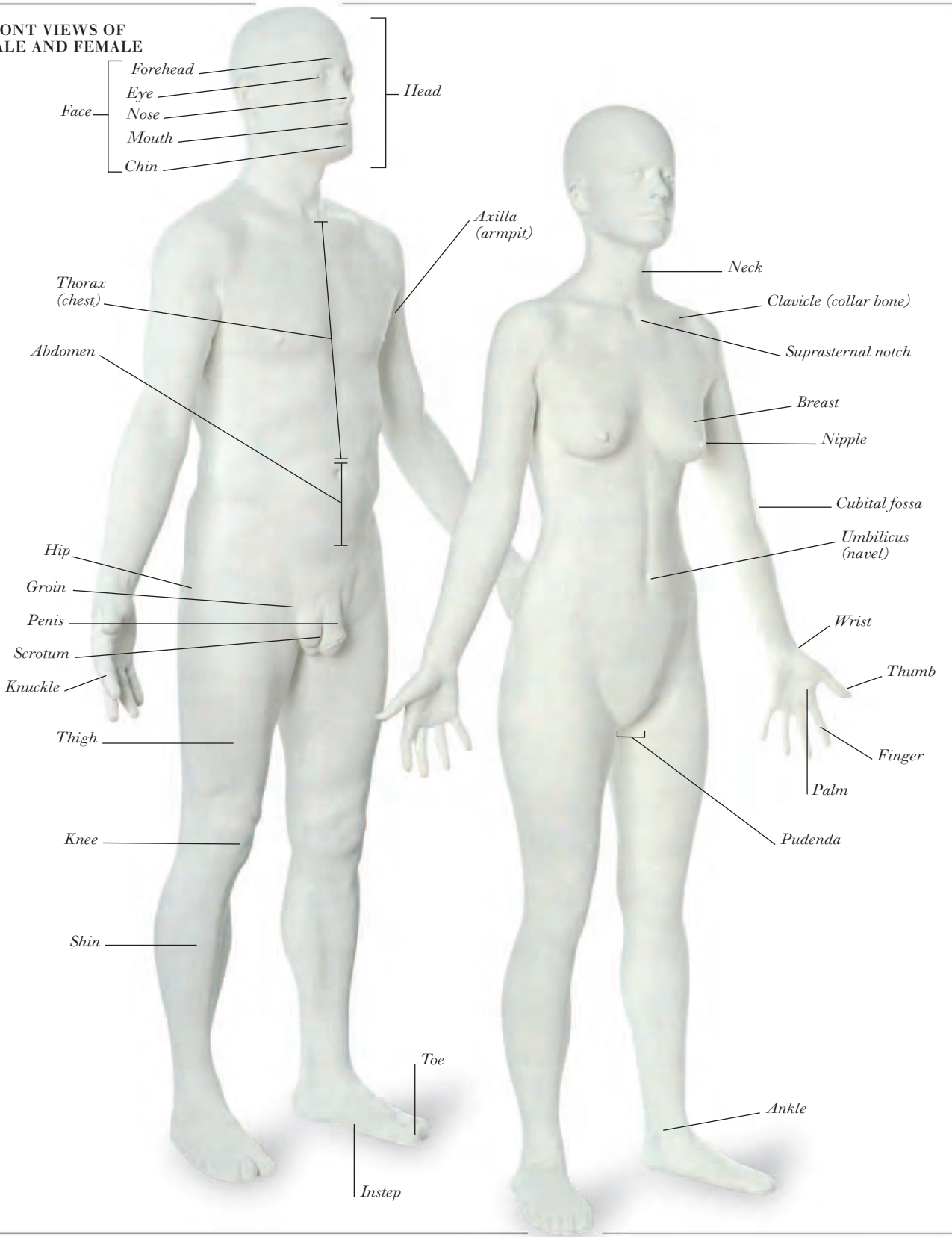
ALTHOUGH THERE IS enormous variation between the external appearances of humans, all bodies contain the same basic features.

The outward form of the human body depends on the size of the skeleton, the shape of the muscles, the thickness of the fat layer beneath the skin, the elasticity or sagginess of the skin, and the person's age and sex. Males tend to be taller than females, with broader shoulders, more body hair, and a different pattern of fat deposits under the skin; the female body tends to be less muscular and has a shallower and wider pelvis to allow for childbirth.

BACK VIEWS OF MALE AND FEMALE



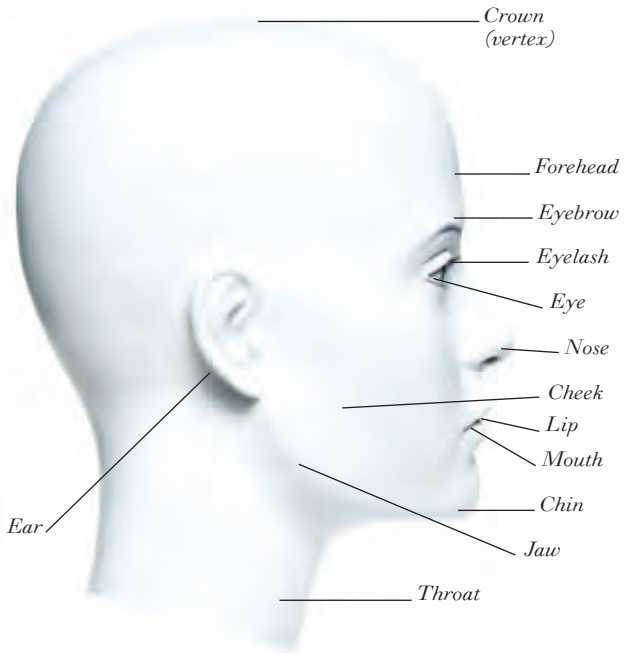
FRONT VIEWS OF MALE AND FEMALE



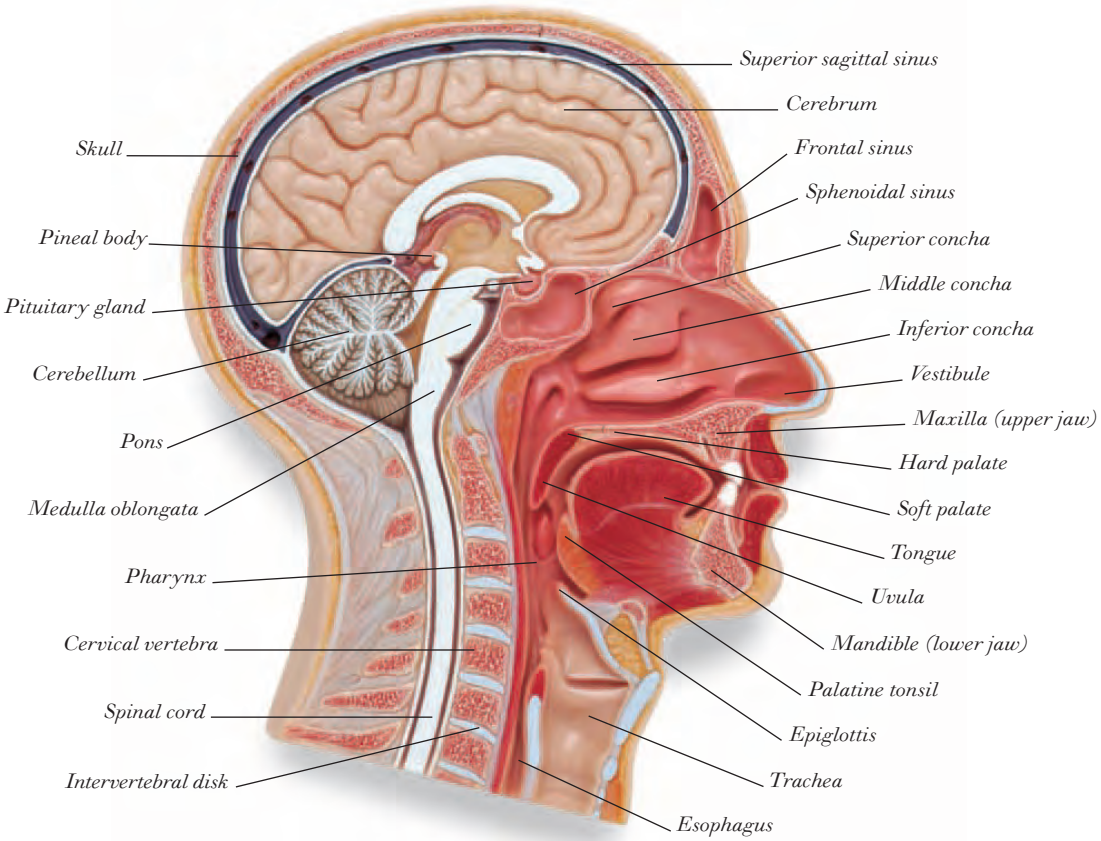
Head

IN A NEWBORN BABY, the head accounts for one-quarter of the total body length; by adulthood, the proportion has reduced to one-eighth. Contained in the head are the body's main sense organs: eyes, ears, olfactory nerves that detect smells, and the taste buds of the tongue. Signals from these organs pass to the body's great coordination center: the brain, housed in the protective, bony dome of the skull. Hair on the head insulates against heat loss, and adult males also grow thick facial hair. The face has three important openings: two nostrils through which air passes, and the mouth, which takes in nourishment and helps form speech. Although all heads are basically similar, differences in the size, shape, and color of features produce an infinite variety of appearances.

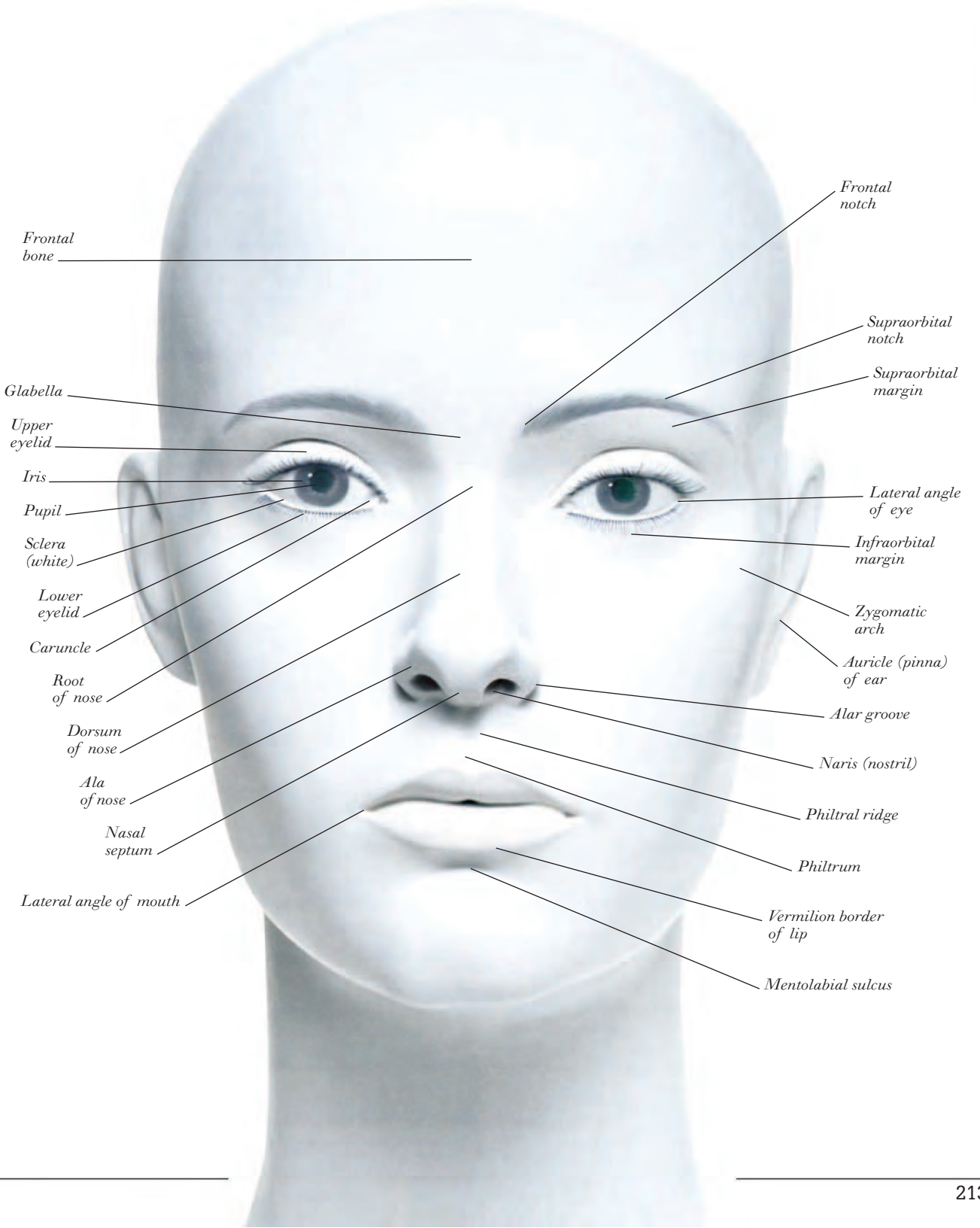
SIDE VIEW OF EXTERNAL FEATURES OF HEAD



SECTION THROUGH HEAD



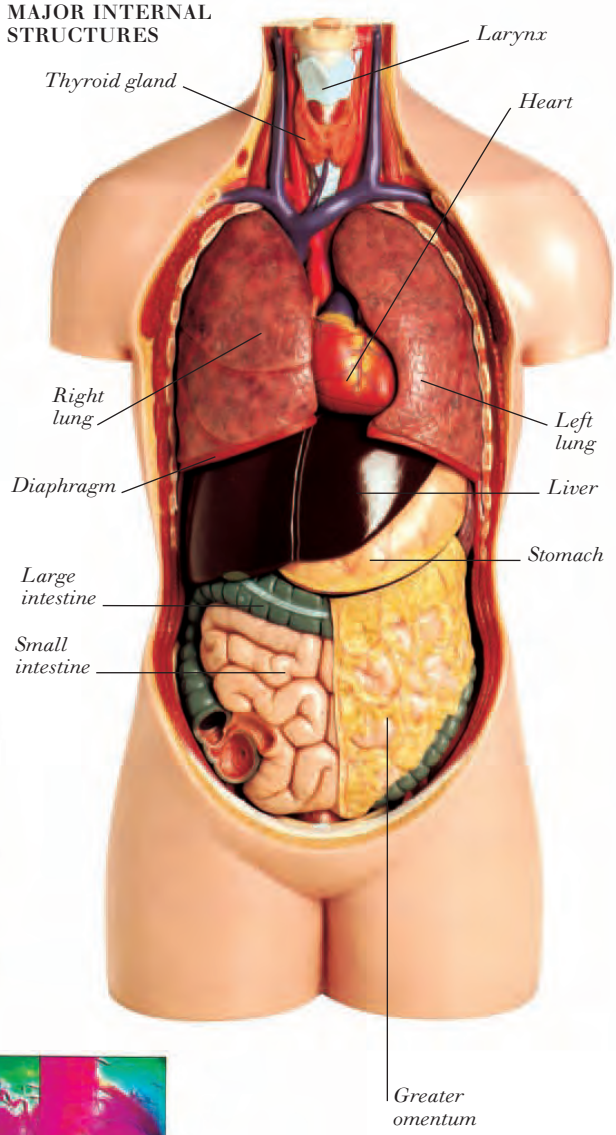
FRONT VIEW OF EXTERNAL FEATURES OF HEAD



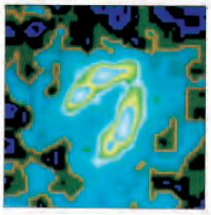
Body organs

ALL THE VITAL BODY ORGANS except for the brain are enclosed within the trunk or torso (the body apart from the head and limbs). The trunk contains two large cavities separated by a muscular sheet called the diaphragm. The upper cavity, known as the thorax or chest cavity, contains the heart and lungs. The lower cavity, called the abdominal cavity, contains the stomach, intestines, liver, and pancreas, which all play a role in digesting food. Also within the trunk are the kidneys and bladder, which are part of the urinary system, and the reproductive organs, which hold the seeds of new human life. Modern imaging techniques, such as contrast X-rays and different types of scans, make it possible to see and study body organs without the need to cut through their protective coverings of skin, fat, muscle, and bone.

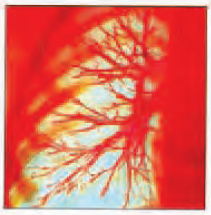
MAJOR INTERNAL STRUCTURES



IMAGING THE BODY



SCINTIGRAM OF HEART CHAMBERS

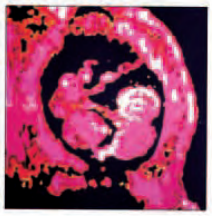


ANGIOGRAM OF RIGHT LUNG

CONTRAST X-RAY OF GALLBLADDER

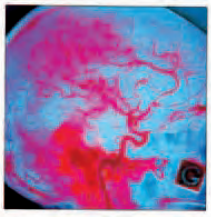
SCINTIGRAM OF NERVOUS SYSTEM

DOUBLE CONTRAST X-RAY OF COLON



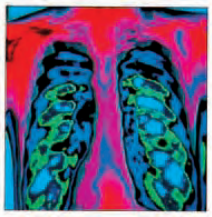
ULTRASOUND SCAN OF TWINS IN UTERUS

ANGIOGRAM OF KIDNEYS

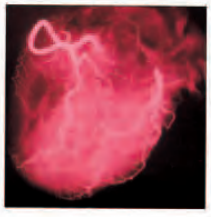


ANGIOGRAM OF ARTERIES OF HEAD

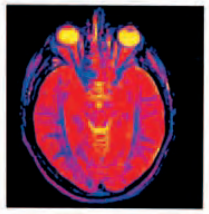
CT SCAN THROUGH FEMALE CHEST



THERMOGRAM OF CHEST REGION

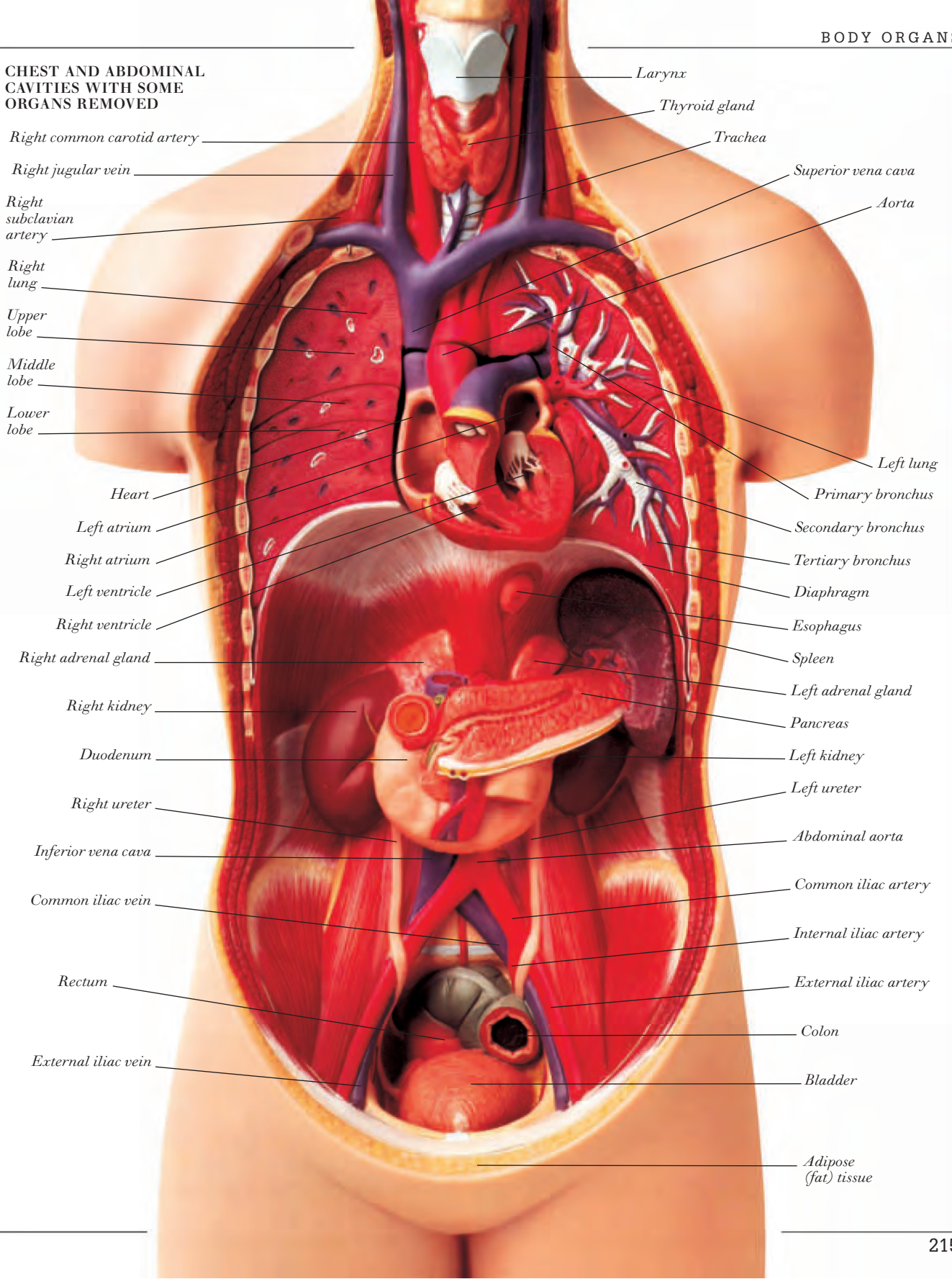


ANGIOGRAM OF ARTERIES OF HEART



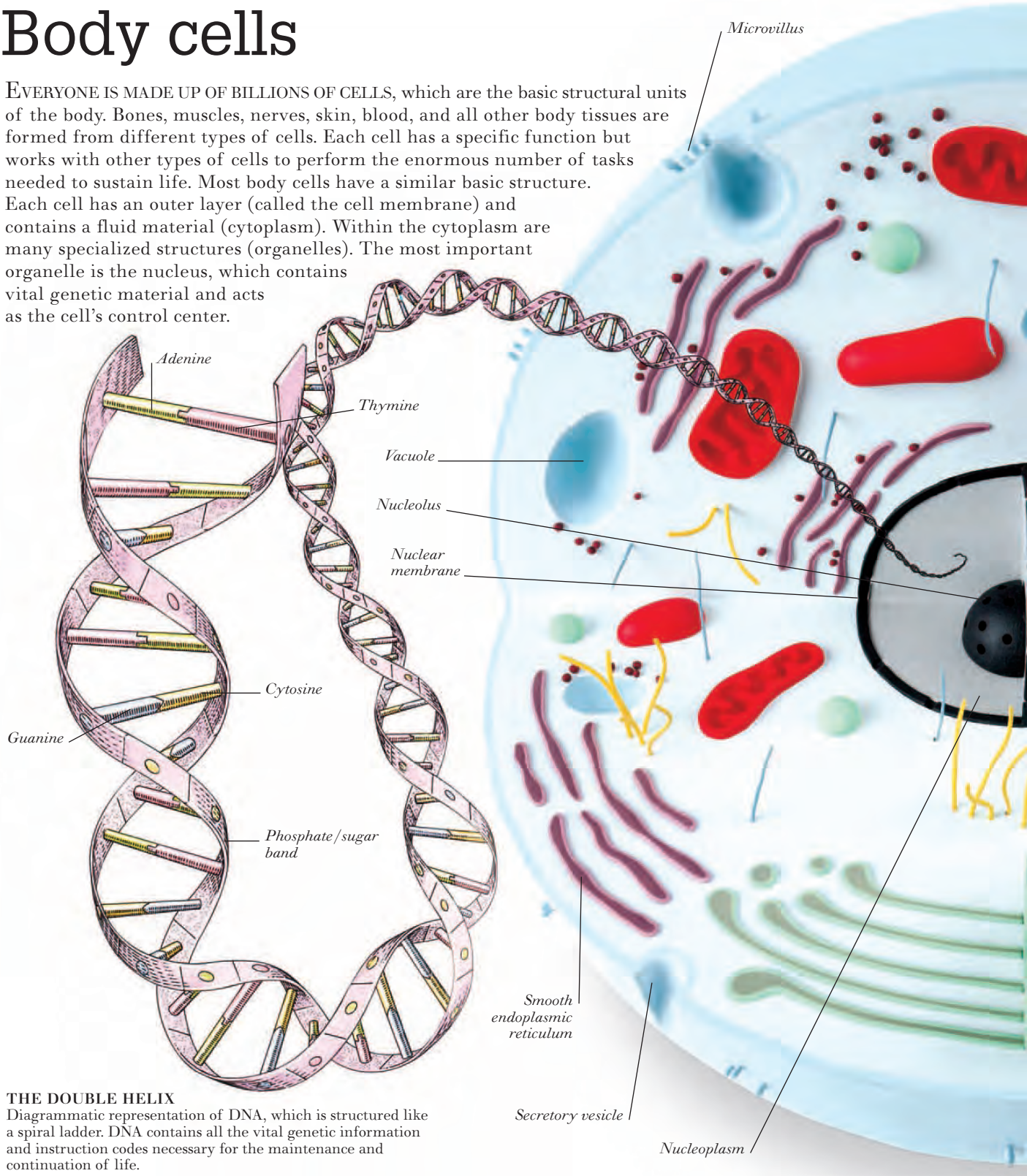
MRI SCAN THROUGH HEAD AT EYE LEVEL

CHEST AND ABDOMINAL CAVITIES WITH SOME ORGANS REMOVED



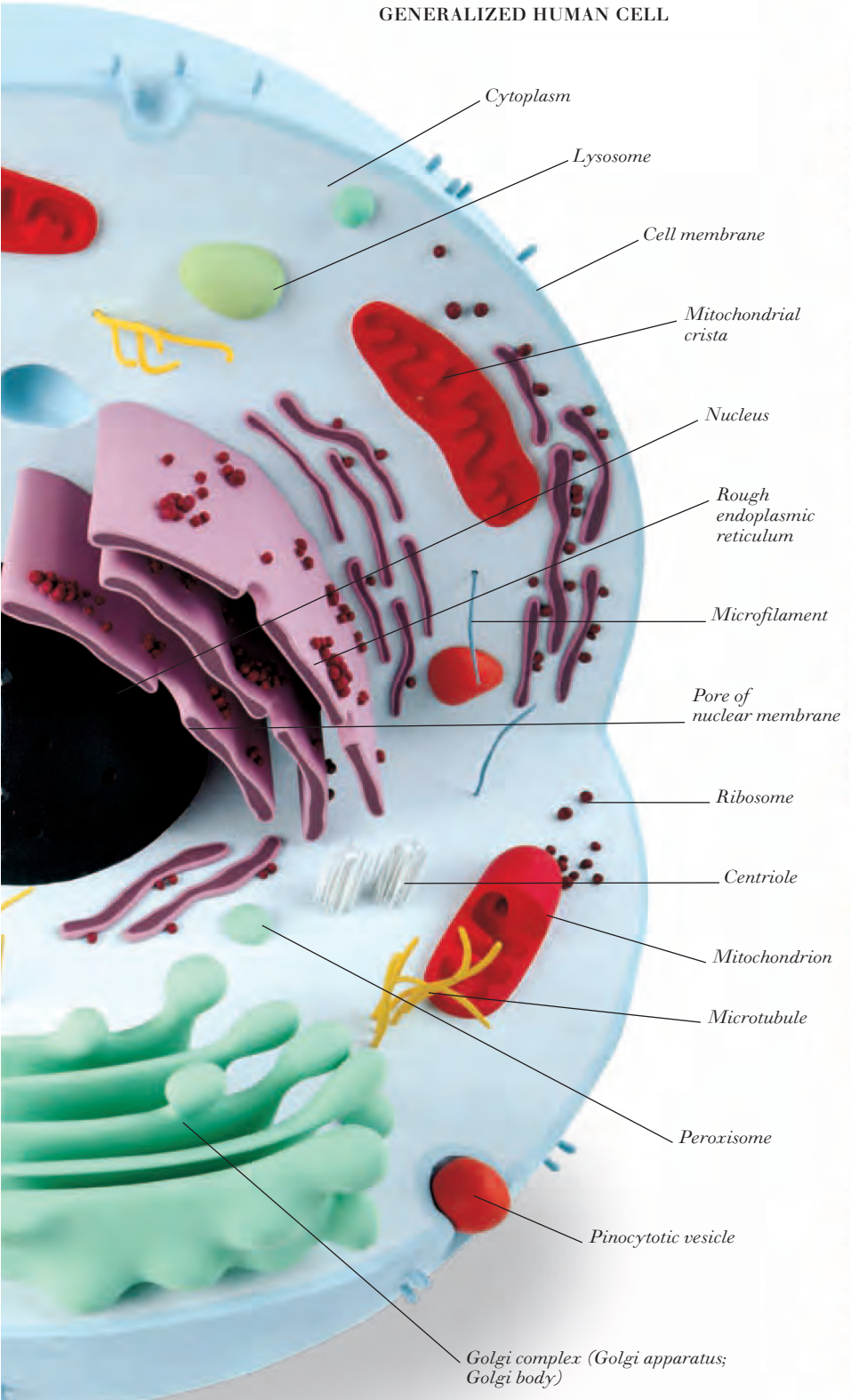
Body cells

EVERYONE IS MADE UP OF BILLIONS OF CELLS, which are the basic structural units of the body. Bones, muscles, nerves, skin, blood, and all other body tissues are formed from different types of cells. Each cell has a specific function but works with other types of cells to perform the enormous number of tasks needed to sustain life. Most body cells have a similar basic structure. Each cell has an outer layer (called the cell membrane) and contains a fluid material (cytoplasm). Within the cytoplasm are many specialized structures (organelles). The most important organelle is the nucleus, which contains vital genetic material and acts as the cell's control center.

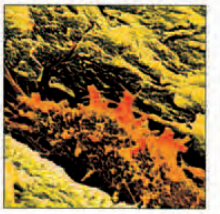


THE DOUBLE HELIX
Diagrammatic representation of DNA, which is structured like a spiral ladder. DNA contains all the vital genetic information and instruction codes necessary for the maintenance and continuation of life.

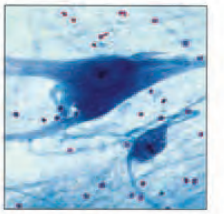
GENERALIZED HUMAN CELL



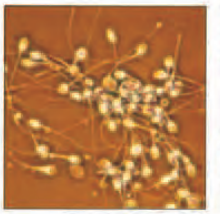
TYPES OF CELLS



BONE-FORMING CELL

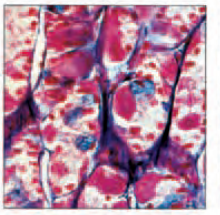


NERVE CELLS IN SPINAL CORD

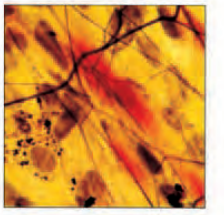


SPERM CELLS IN SEMEN

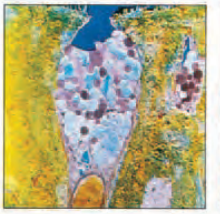
SECRETORY THYROID GLAND CELLS



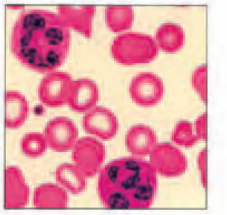
ACID-SECRETING STOMACH CELLS



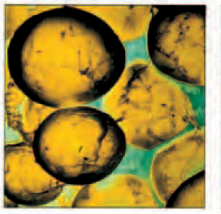
CONNECTIVE TISSUE CELLS



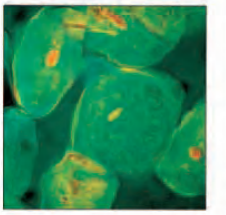
MUCUS-SECRETING DUODENAL CELLS



RED AND TWO WHITE BLOOD CELLS



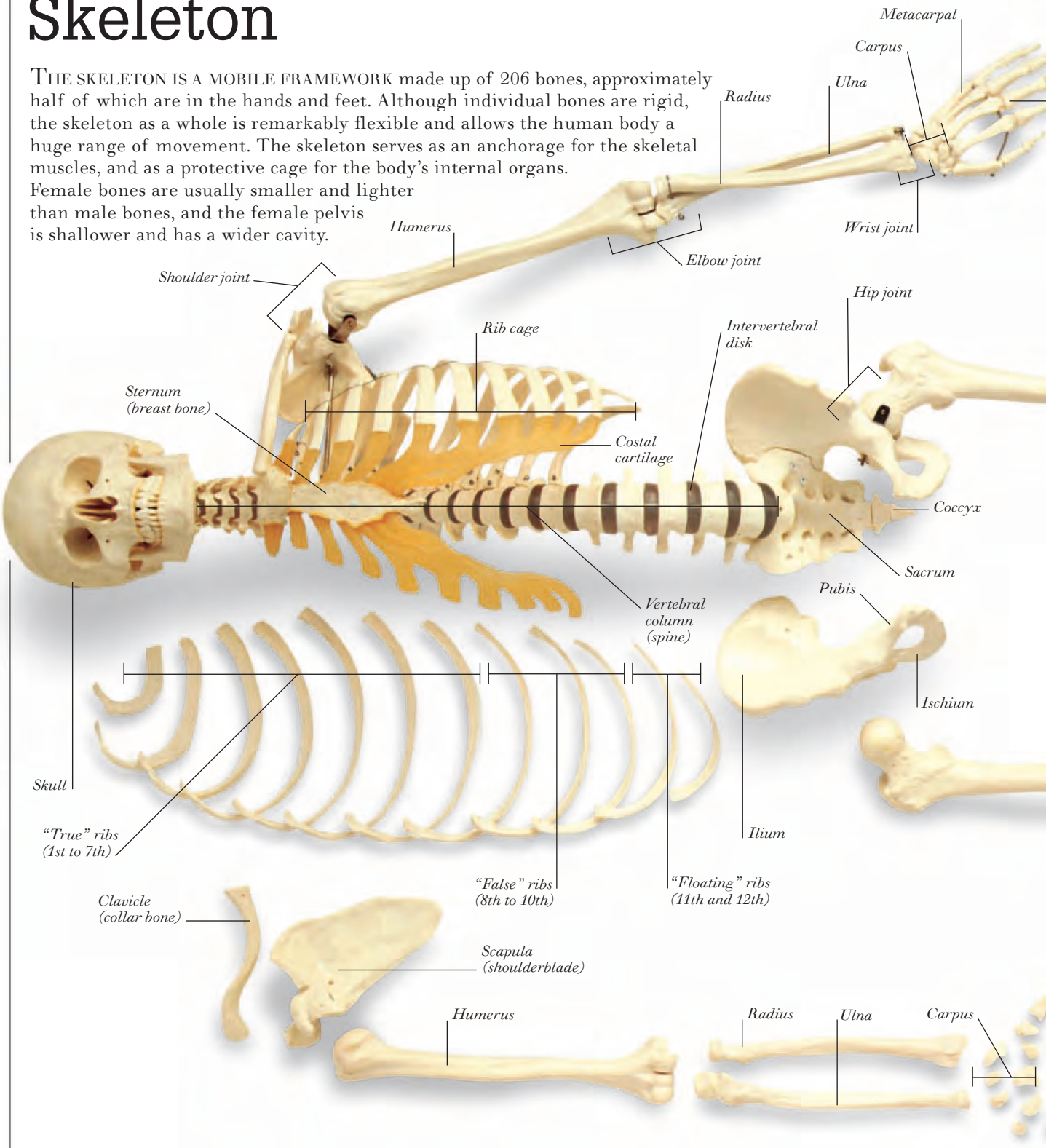
FAT CELLS IN ADIPOSE TISSUE

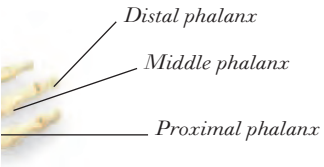


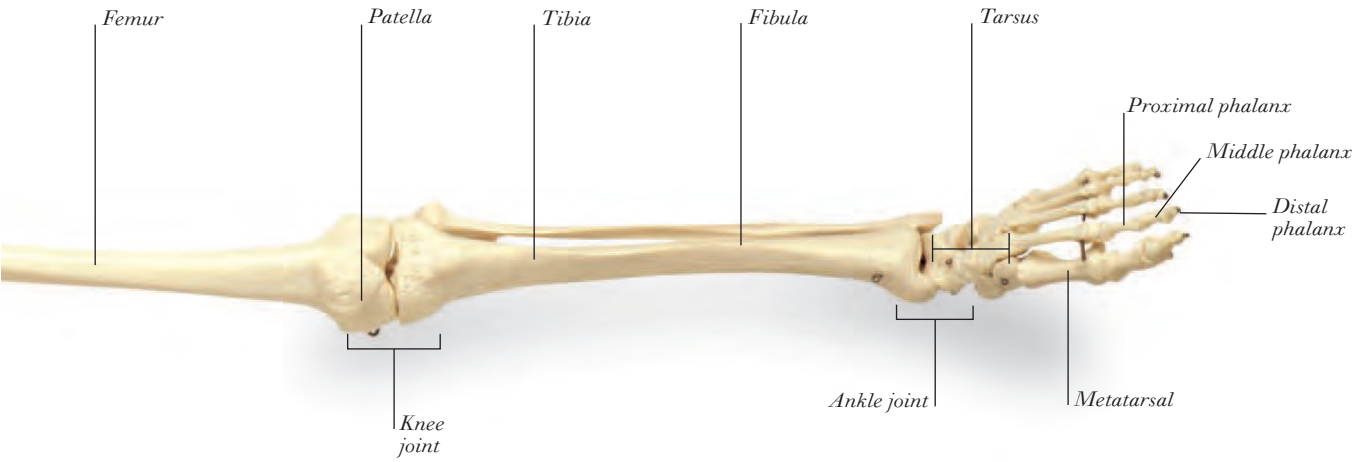
EPITHELIAL CELLS IN CHEEK

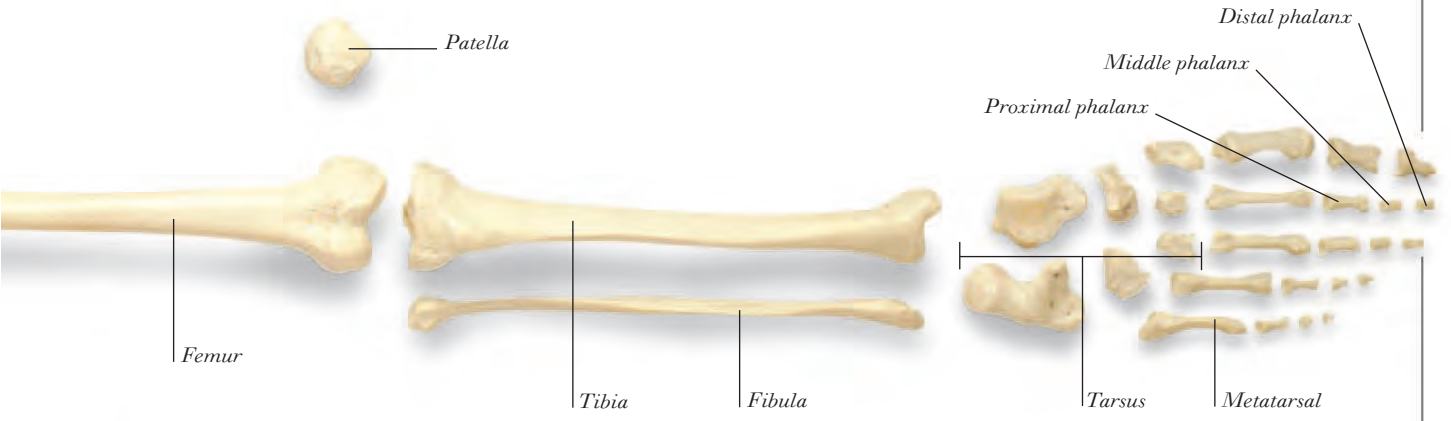
Skeleton

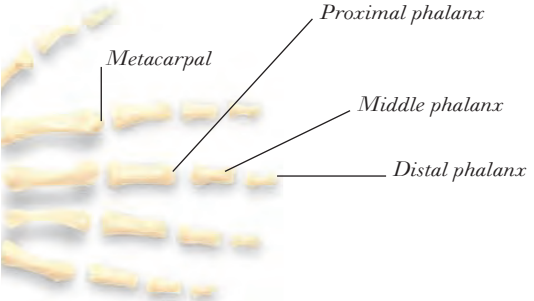
THE SKELETON IS A MOBILE FRAMEWORK made up of 206 bones, approximately half of which are in the hands and feet. Although individual bones are rigid, the skeleton as a whole is remarkably flexible and allows the human body a huge range of movement. The skeleton serves as an anchorage for the skeletal muscles, and as a protective cage for the body's internal organs. Female bones are usually smaller and lighter than male bones, and the female pelvis is shallower and has a wider cavity.



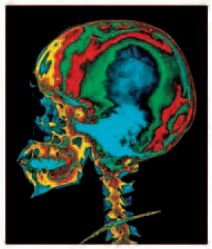

Distal phalanx
Middle phalanx
Proximal phalanx


Femur
Patella
Tibia
Fibula
Tarsus
Proximal phalanx
Middle phalanx
Distal phalanx
Knee joint
Ankle joint
Metatarsal


Patella
Distal phalanx
Middle phalanx
Proximal phalanx
Femur
Tibia
Fibula
Tarsus
Metatarsal

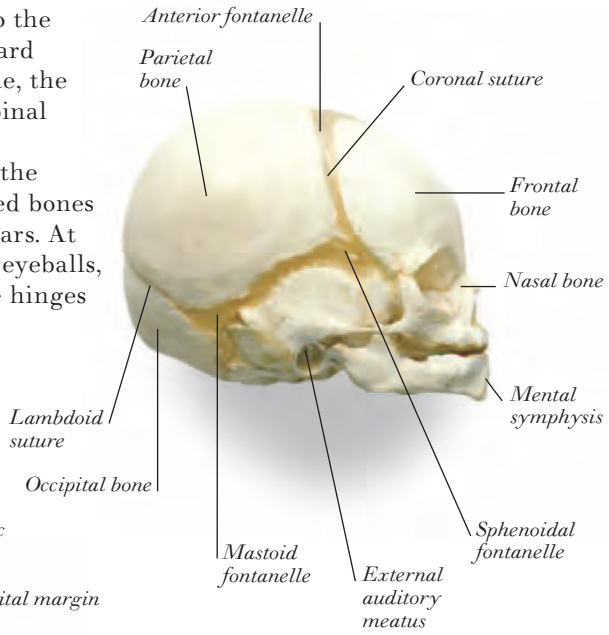

Proximal phalanx
Metacarpal
Middle phalanx
Distal phalanx

Skull

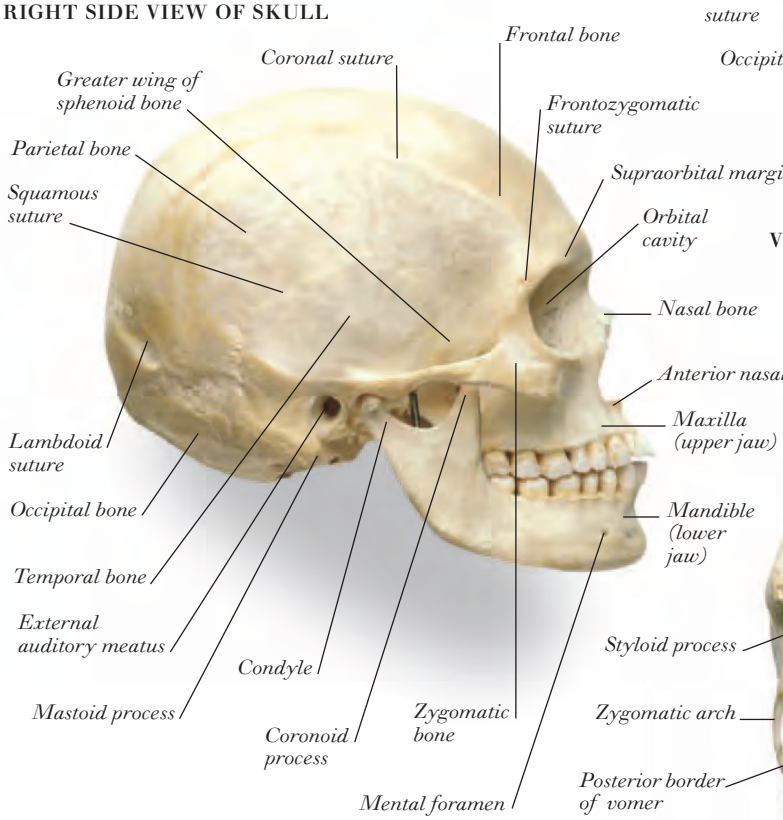


THE SKULL is the most complicated bony structure of the body but every feature serves a purpose. Internally, the main hollow chamber of the skull has three levels that support the brain, with every bump and hollow corresponding to the shape of the brain. Underneath and toward the back of the skull is a large round hole, the foramen magnum, through which the spinal cord passes. To the front of this are many smaller openings through which nerves, arteries, and veins pass to and from the brain. The roof of the skull is formed from four thin, curved bones that are firmly fixed together from the age of about two years. At the front of the skull are the two orbits, which contain the eyeballs, and a central hole for the airway of the nose. The jaw bone hinges on either side at ear level.

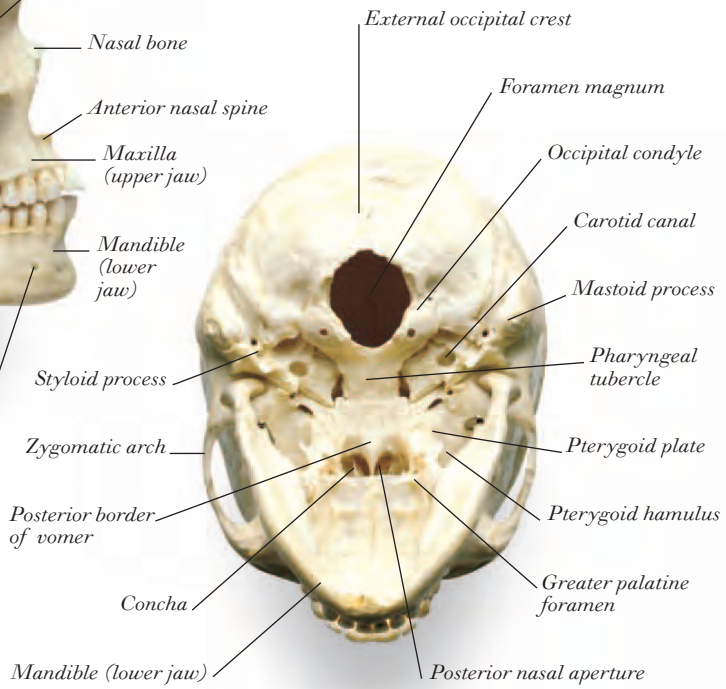
RIGHT SIDE VIEW OF A FETAL SKULL



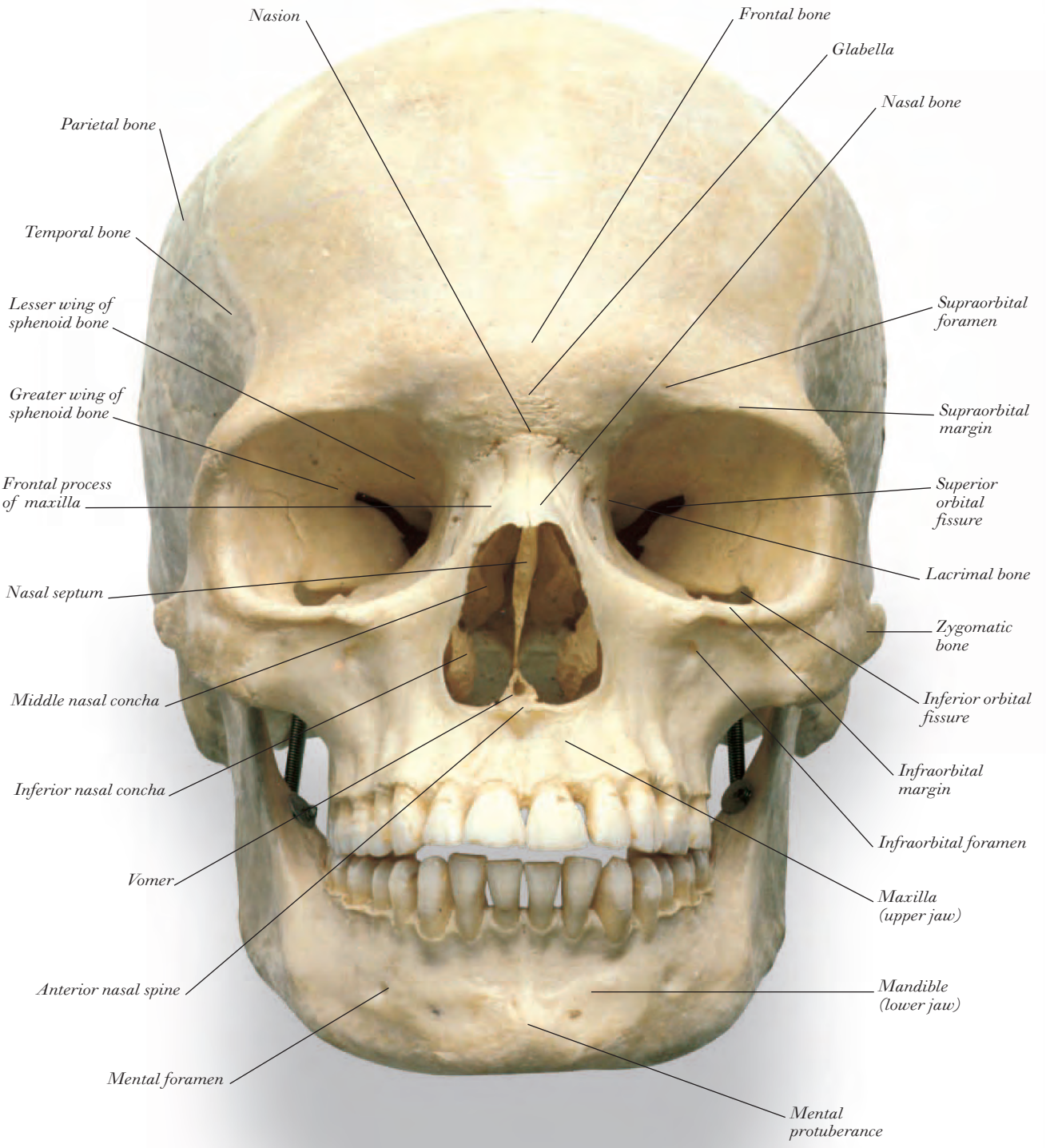
RIGHT SIDE VIEW OF SKULL



VIEW OF SKULL FROM BELOW



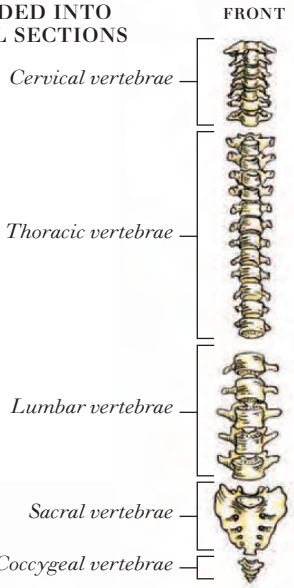
FRONT VIEW OF SKULL



Spine

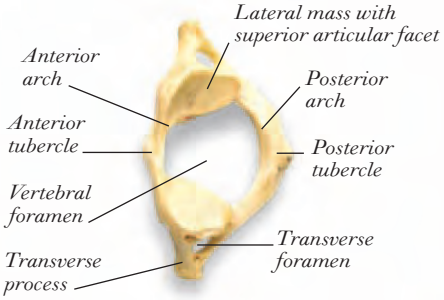
THE SPINE (OR VERTEBRAL COLUMN) has two main functions: it serves as a protective surrounding for the delicate spinal cord and forms the supporting back bone of the skeleton. The spine consists of 24 separate differently shaped bones (vertebrae) with a curved, triangular bone (the sacrum) at the bottom. The sacrum is made up of fused vertebrae; at its lower end is a small tail-like structure made up of tiny bones collectively called the coccyx. Between each pair of vertebrae is a disk of cartilage that cushions the bones during movement. The top two vertebrae differ in appearance from the others and work as a pair: the first, called the atlas, rotates around a stout vertical peg on the second, the axis. This arrangement allows the skull to move freely up and down, and from side to side.

SPINE DIVIDED INTO VERTEBRAL SECTIONS

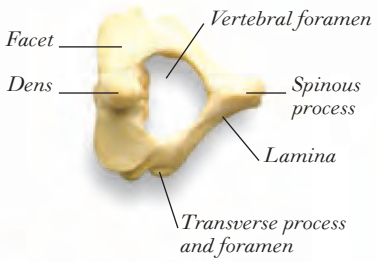


TYPES OF VERTEBRAE (VIEWED FROM ABOVE)

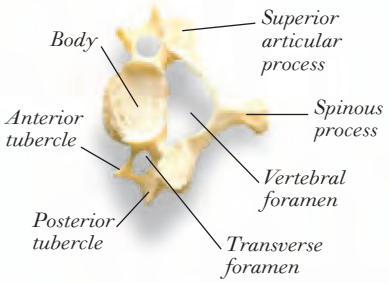
ATLAS

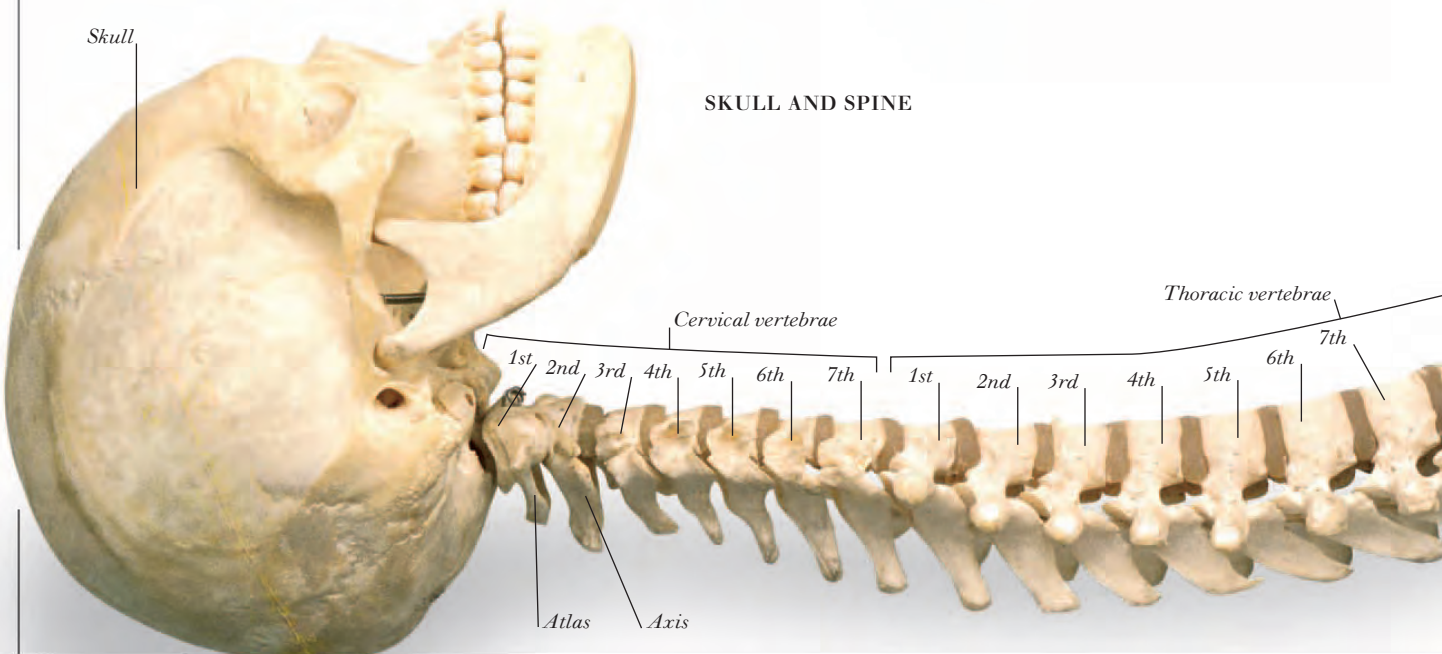


AXIS



CERVICAL VERTEBRA



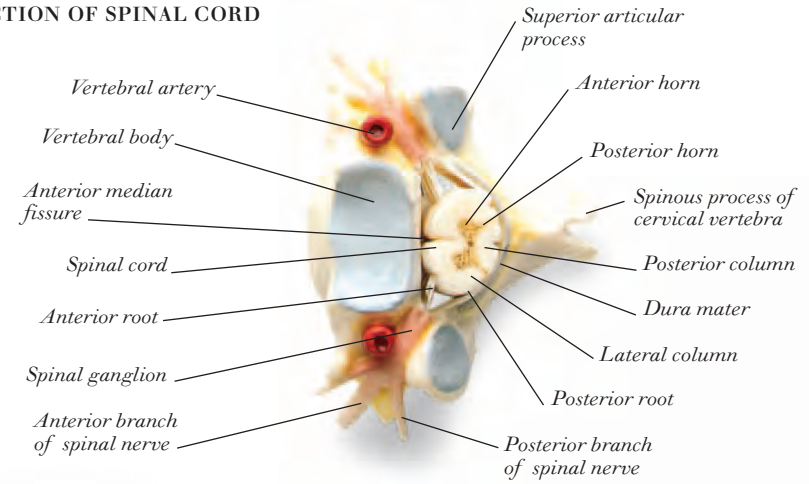


SKULL AND SPINE

RIGHT SIDE

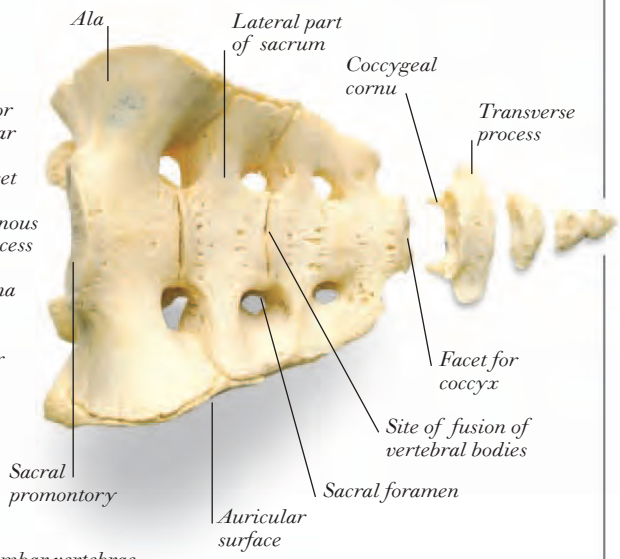
BACK

CERVICAL VERTEBRA AND SECTION OF SPINAL CORD

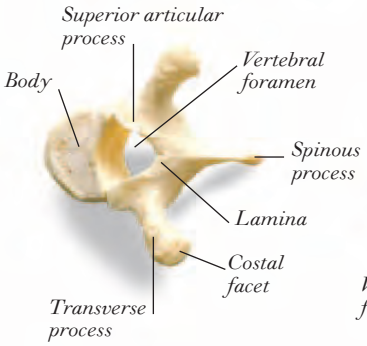


SACRUM

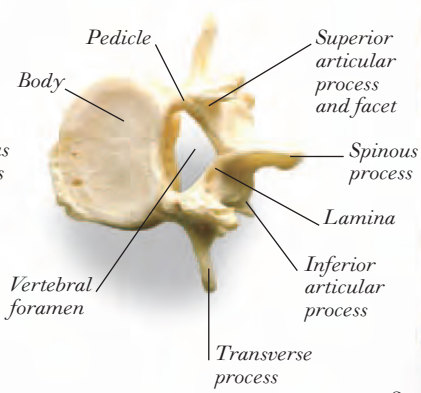
COCCYX

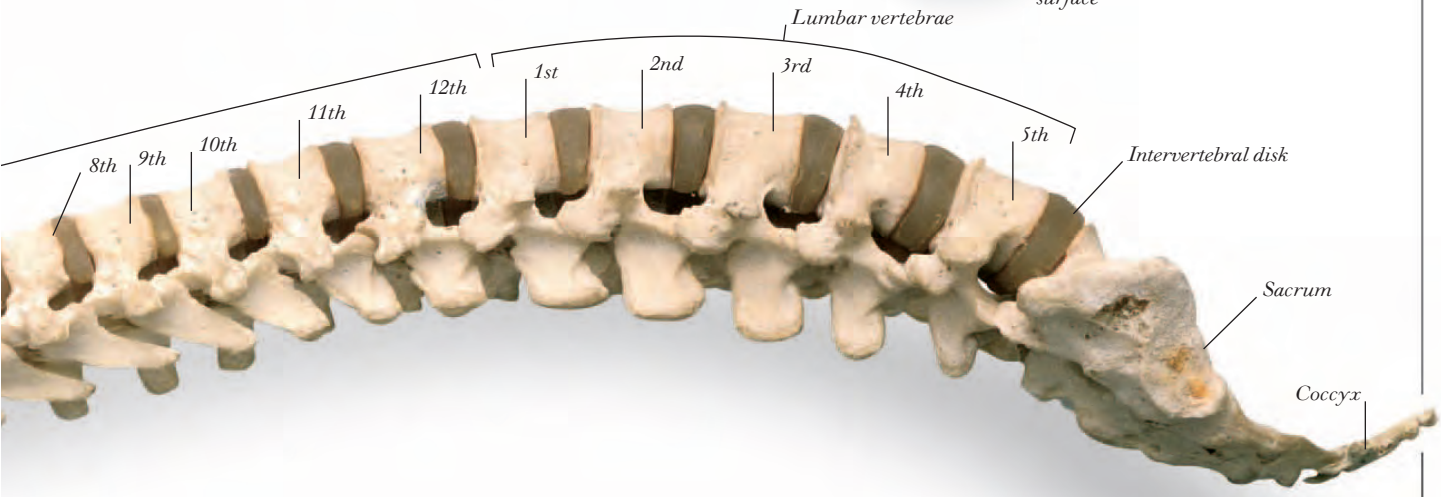


THORACIC VERTEBRA



LUMBAR VERTEBRA

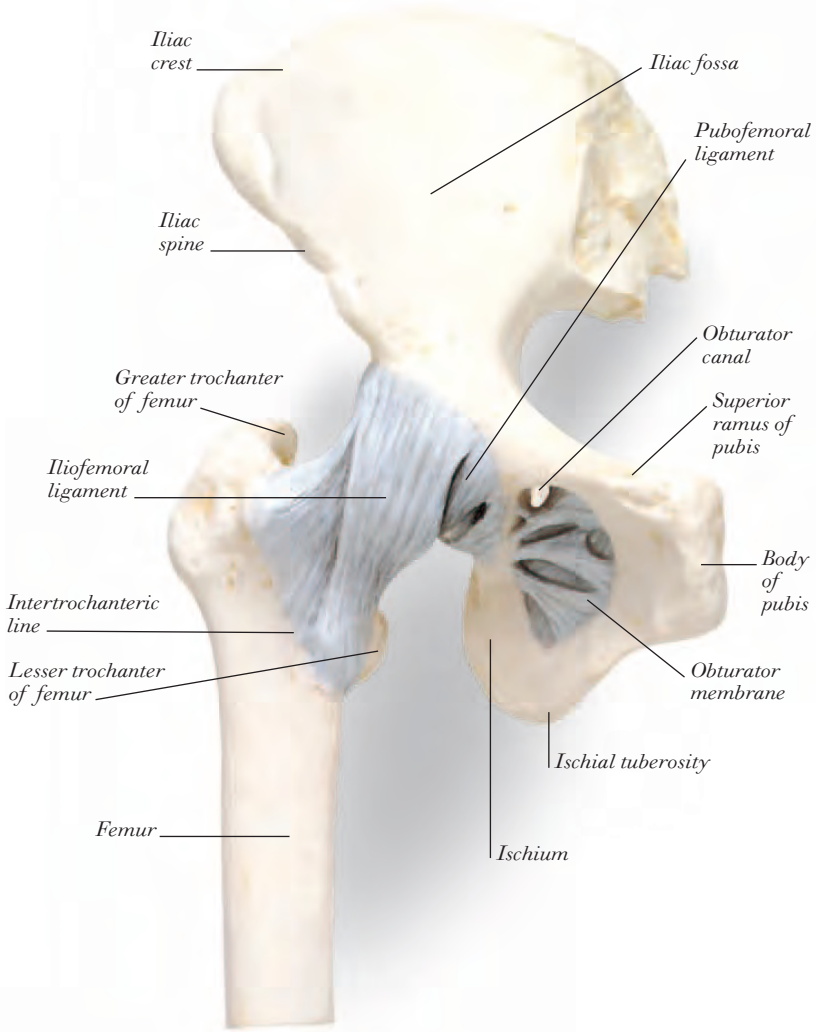




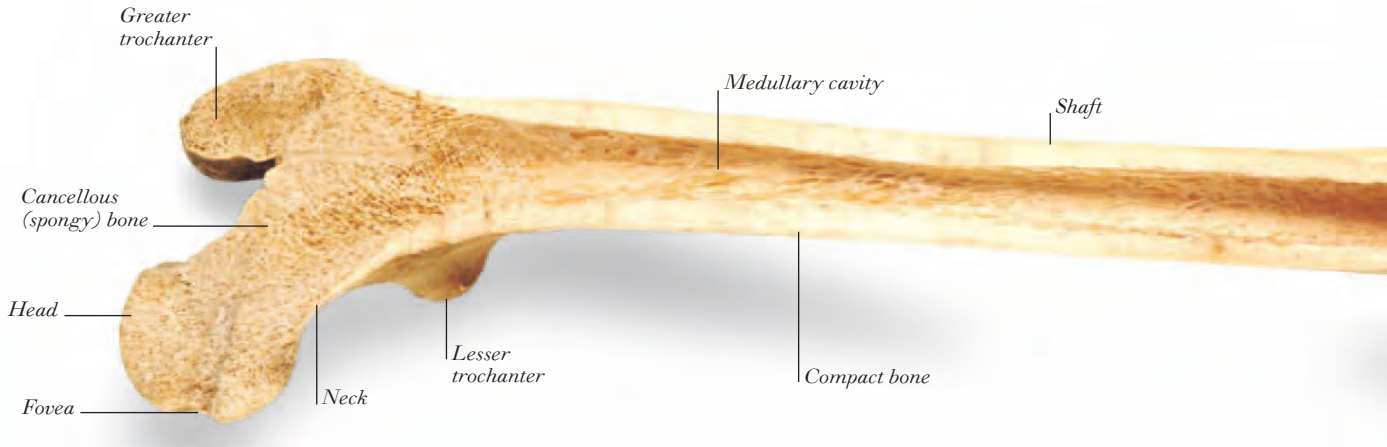
Bones and joints

BONES FORM the body's hard, strong skeletal framework. Each bone has a hard, compact exterior surrounding a spongy, lighter interior. The long bones of the arms and legs, such as the femur (thigh bone), have a central cavity containing bone marrow. Bones are composed chiefly of calcium, phosphorus, and a fibrous substance known as collagen. Bones meet at joints, which are of several different types. For example, the hip is a ball-and-socket joint that allows the femur a wide range of movement, whereas finger joints are simple hinge joints that allow only bending and straightening. Joints are held in place by bands of tissue called ligaments. Movement of joints is facilitated by the smooth hyaline cartilage that covers the bone ends and by the synovial membrane that lines and lubricates the joint.

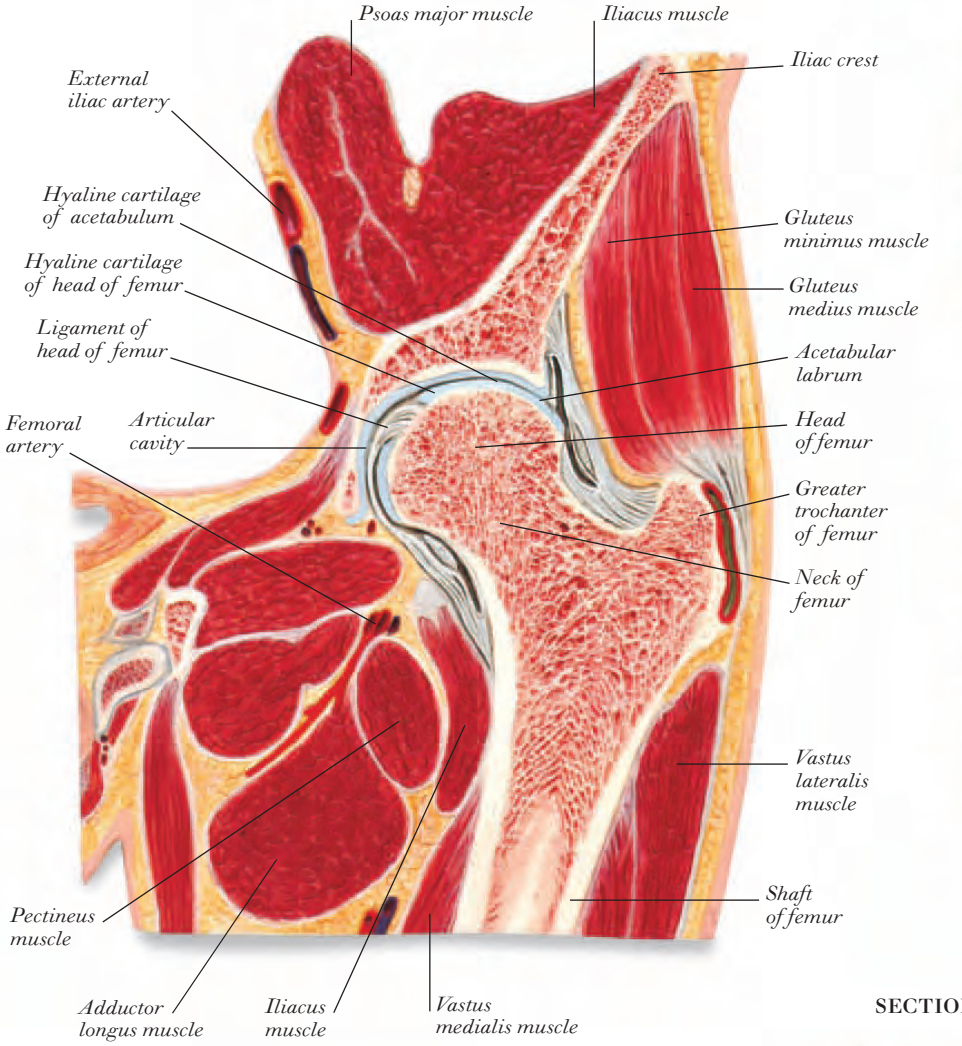
LIGAMENTS SURROUNDING HIP JOINT



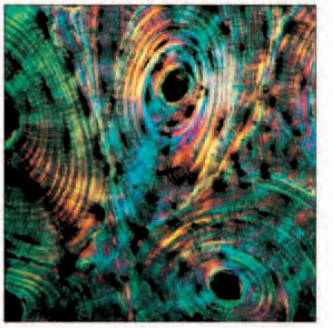
SECTION THROUGH LEFT FEMUR



SECTION THROUGH HIP JOINT

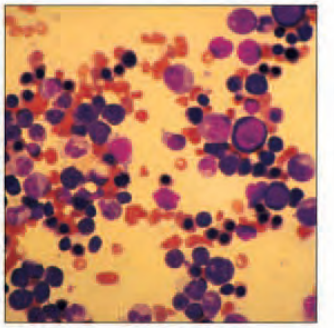


SECTION OF COMPACT BONE



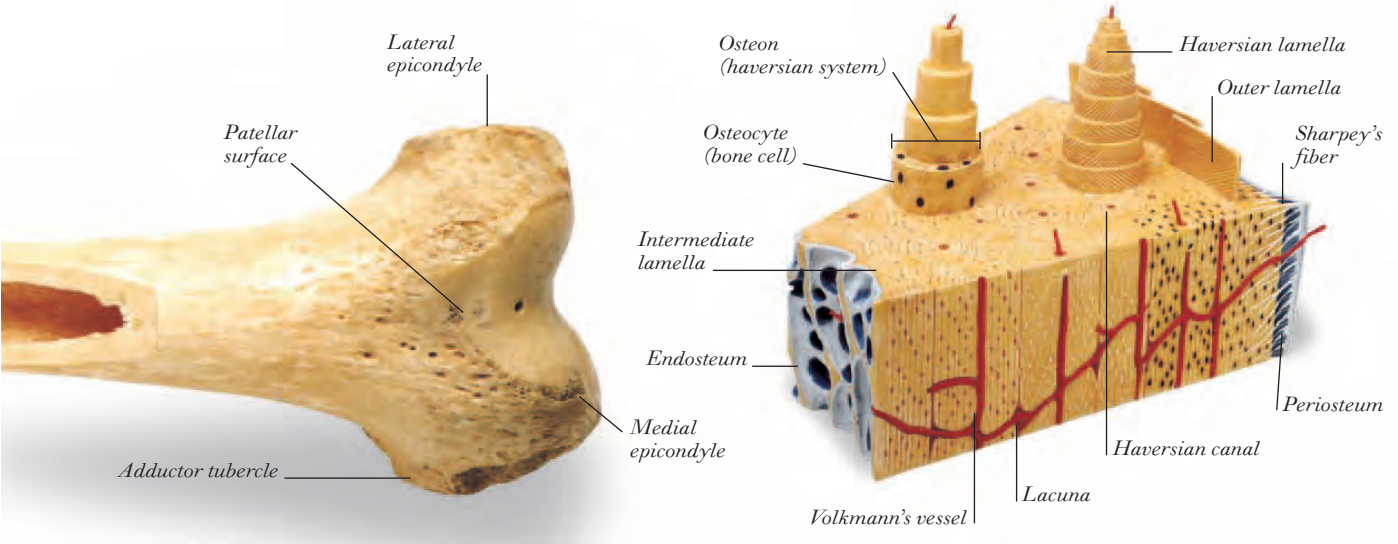
Parallel rows of concentric bony layers make up this strong material.

BONE MARROW SMEAR



Composed mainly of red and white blood cells, marrow fills the cavities of bones.

SECTION THROUGH LONG BONE

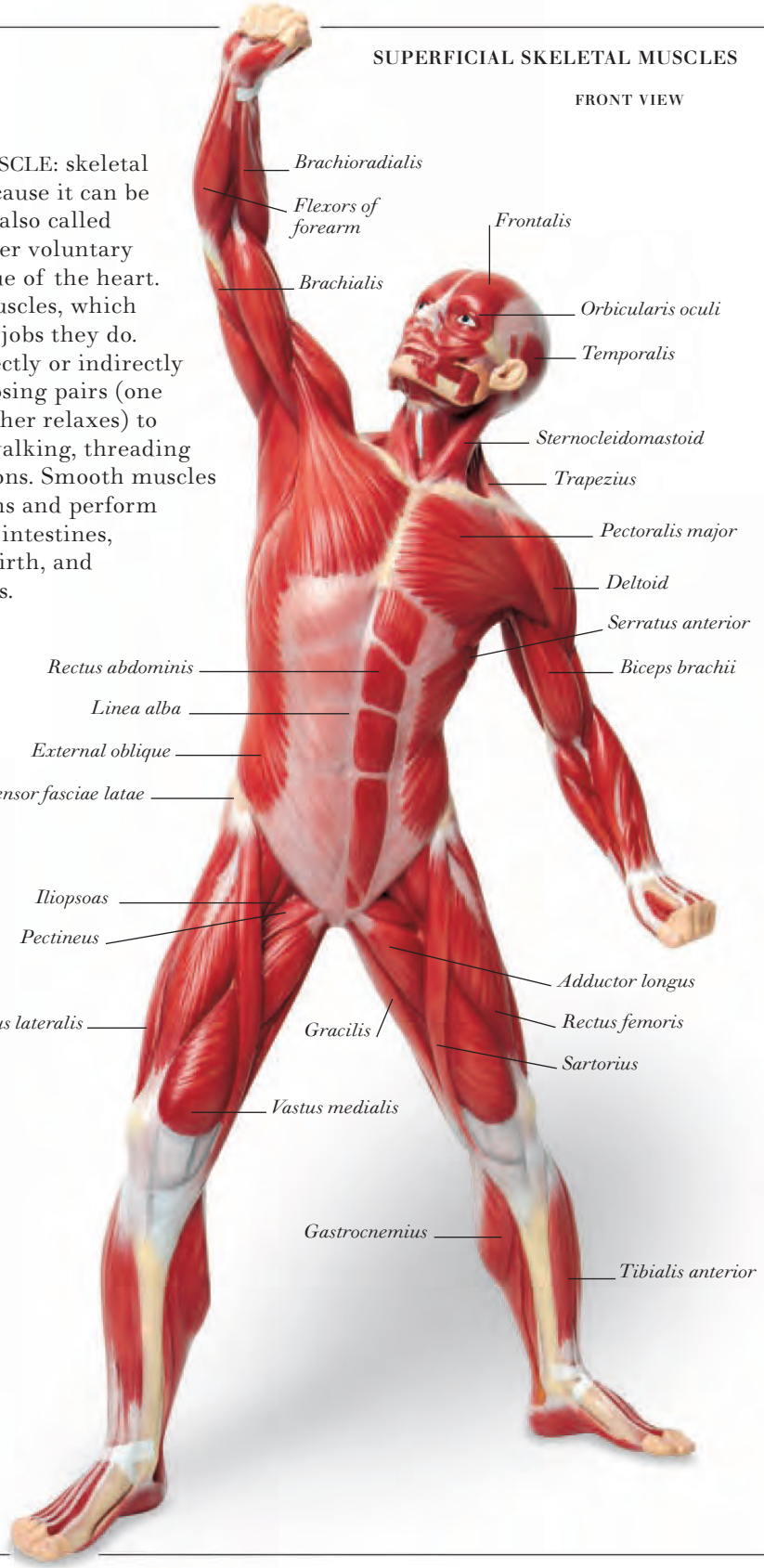


Muscles 1

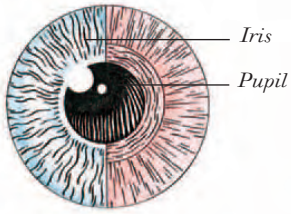
THERE ARE THREE MAIN TYPES OF MUSCLE: skeletal muscle (also called voluntary muscle because it can be consciously controlled); smooth muscle (also called involuntary muscle because it is not under voluntary control); and the specialized muscle tissue of the heart. Humans have more than 600 skeletal muscles, which differ in size and shape according to the jobs they do. Skeletal muscles are attached either directly or indirectly (via tendons) to bones, and work in opposing pairs (one muscle in the pair contracts while the other relaxes) to produce body movements as diverse as walking, threading a needle, and an array of facial expressions. Smooth muscles occur in the walls of internal body organs and perform actions such as forcing food through the intestines, contracting the uterus (womb) in childbirth, and pumping blood through the blood vessels.

SUPERFICIAL SKELETAL MUSCLES

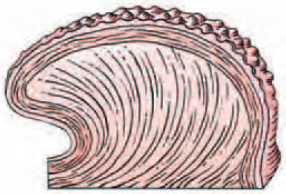
FRONT VIEW



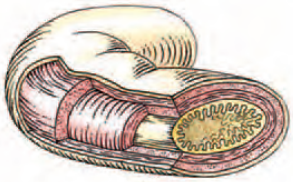
SOME OTHER MUSCLES IN THE BODY



IRIS
The muscle fibers contract and dilate (expand) to alter pupil size.

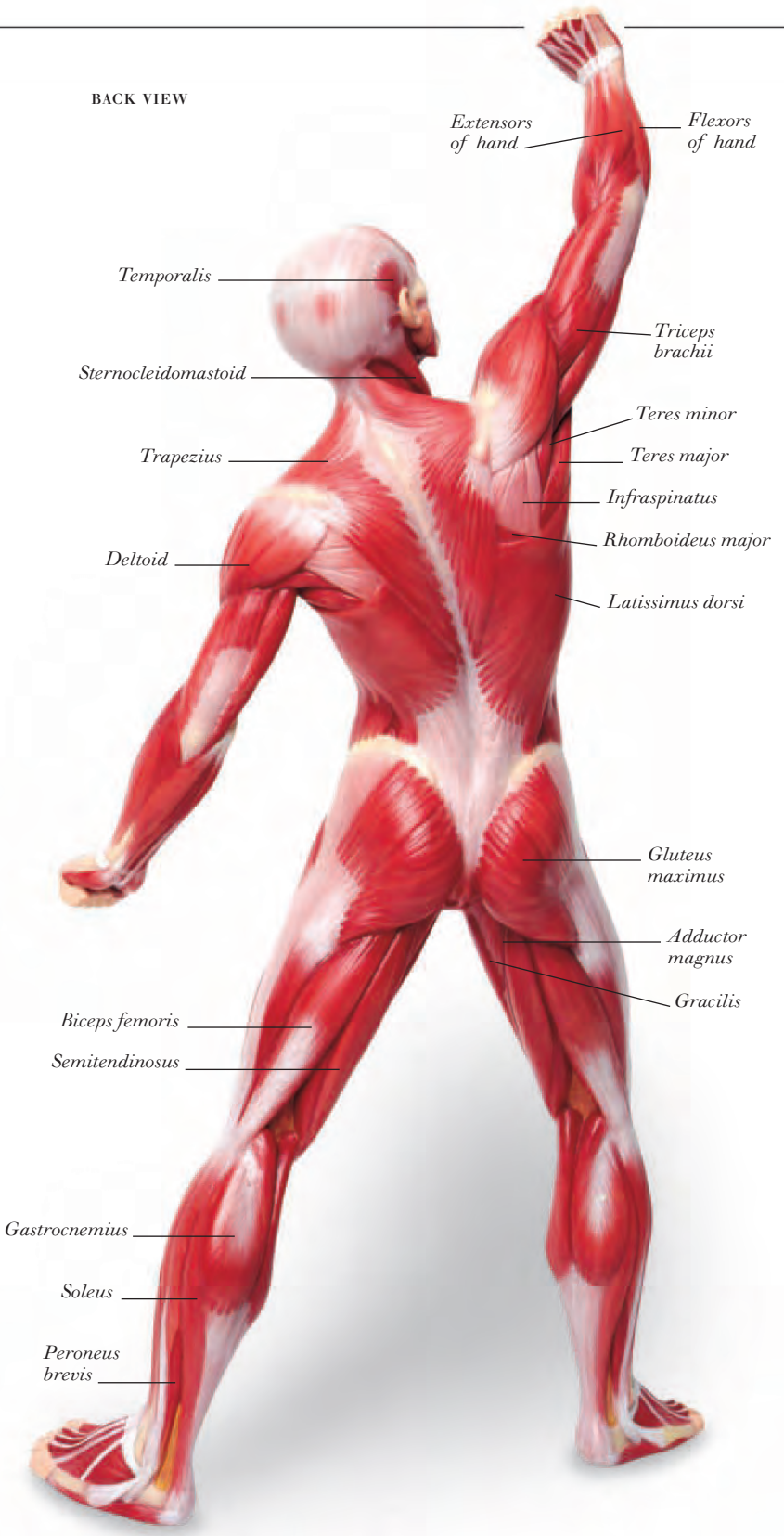


TONGUE
Interlacing layers of muscle allow great mobility.



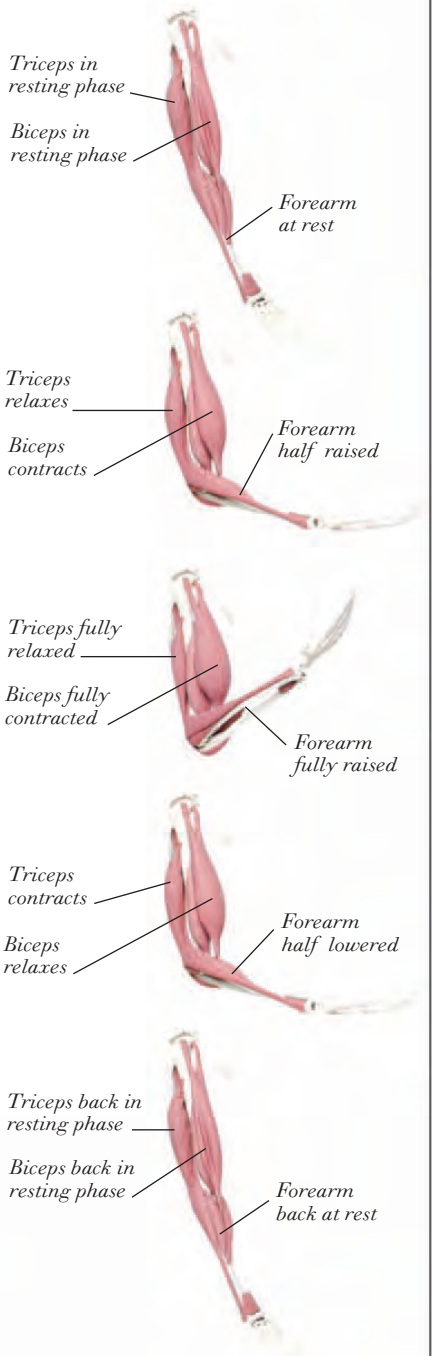
ILEUM
Opposing muscle layers transport semidigested food.

BACK VIEW



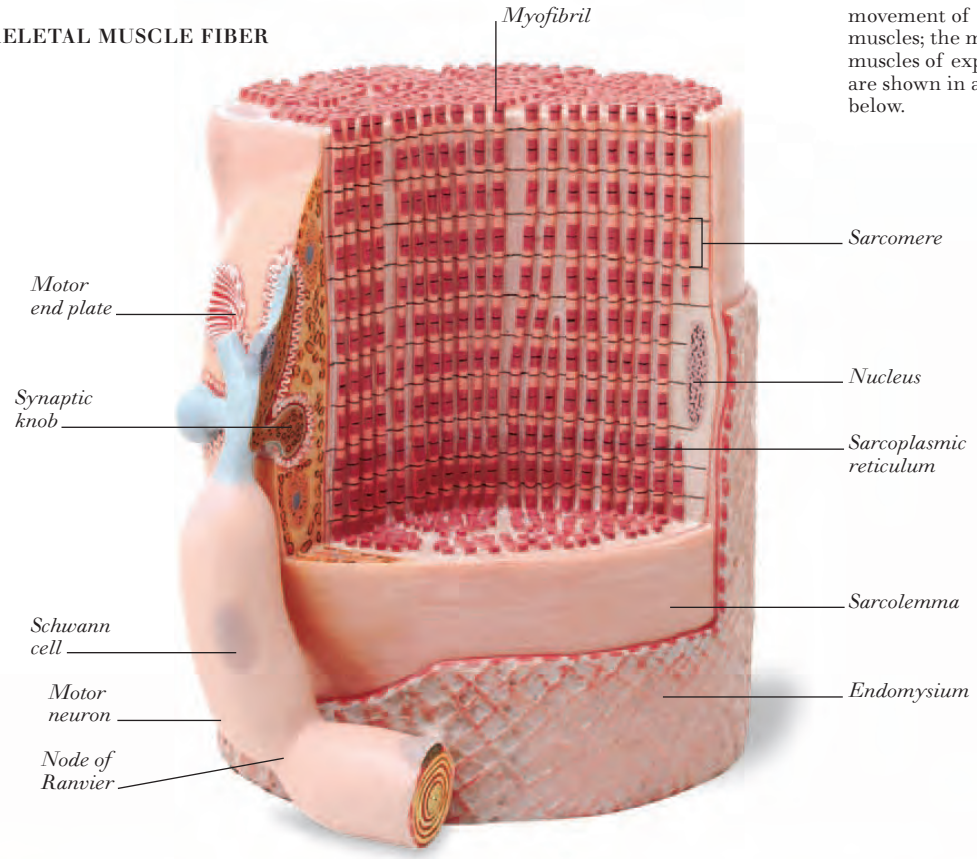
MOVEMENT OF THE FOREARM

Controlled movement of the limbs relies on coordinated relaxation and contraction of opposing muscles. To raise the forearm, the biceps (two-rooted muscle) contracts and shortens while the triceps (three-rooted muscle) relaxes; the reverse occurs when the forearm is lowered.



Muscles 2

SKELETAL MUSCLE FIBER



MUSCLES OF FACIAL EXPRESSION

A single expression is the result of movement of many muscles; the main muscles of expression are shown in action below.

FRONTALIS

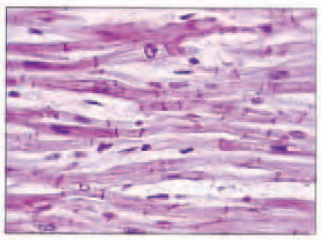
CORRUGATOR SUPERCILII

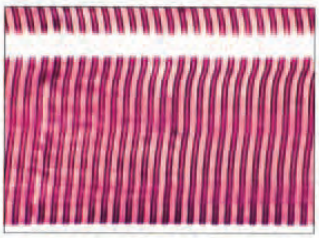
ORBICULARIS ORIS

ZYGOMATICUS MAJOR

DEPRESSOR ANGULI ORIS

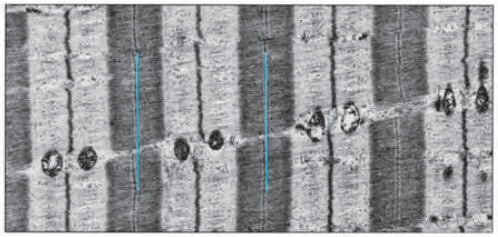
TYPES OF MUSCLE

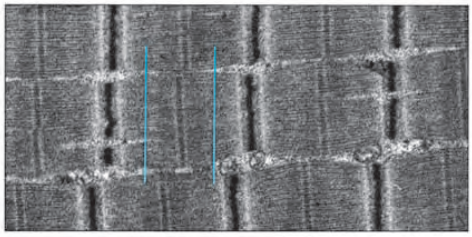

CARDIAC MUSCLE


SKELETAL MUSCLE

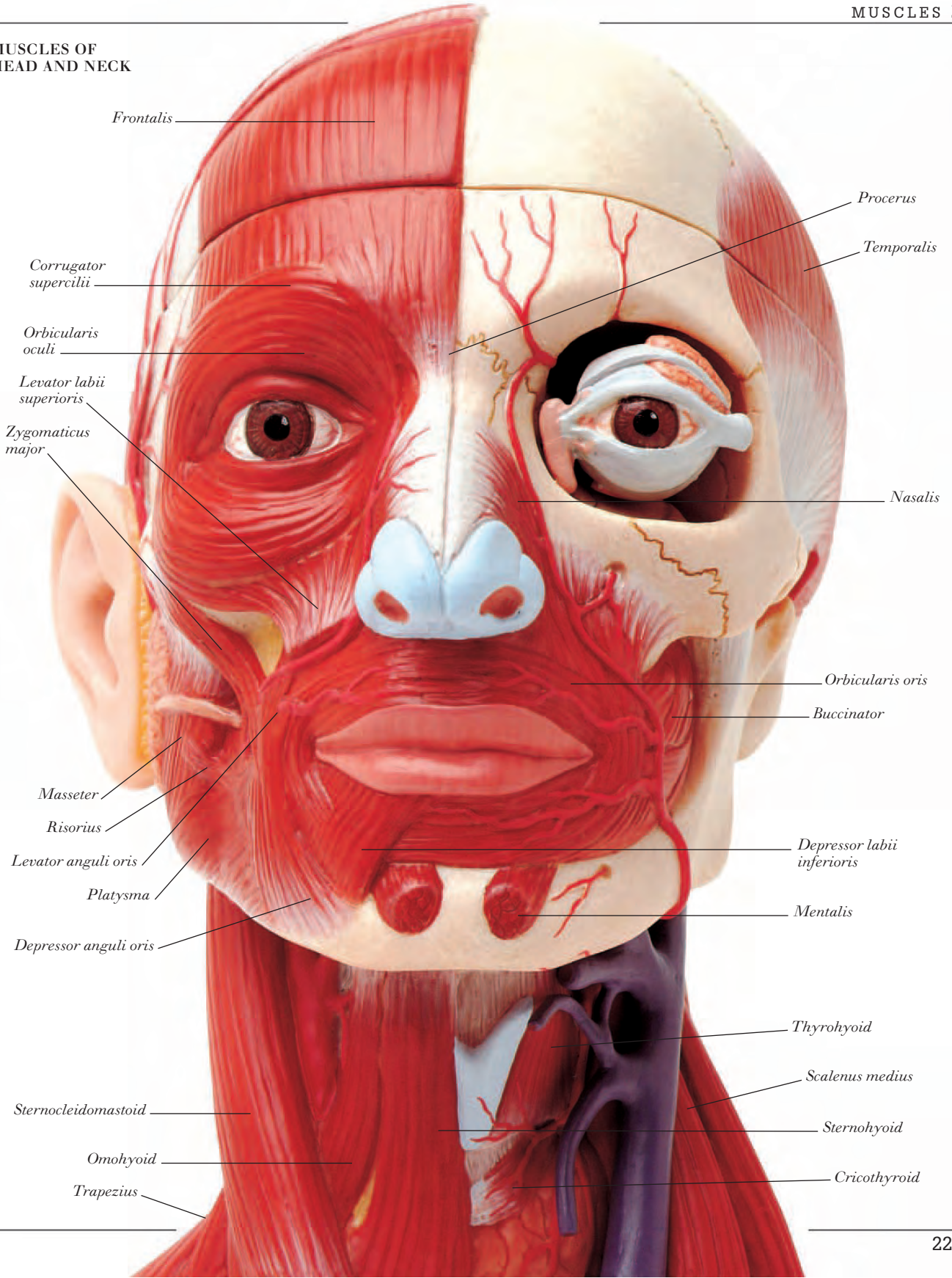
SMOOTH MUSCLE

CONTRACTION OF SKELETAL MUSCLE


RELAXED STATE


CONTRACTED STATE

MUSCLES OF HEAD AND NECK



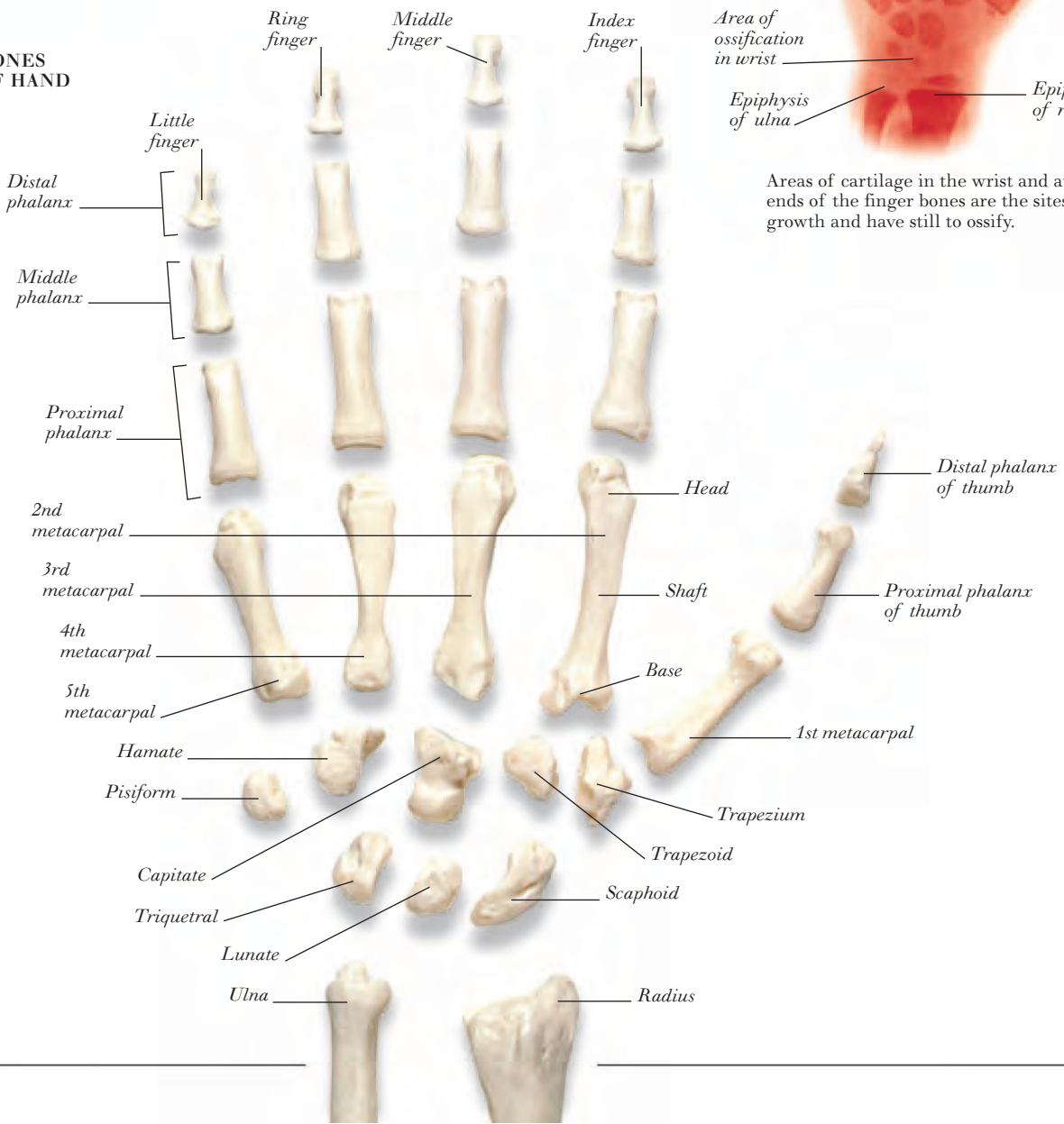
Hands

THE HUMAN HAND is an extremely versatile tool, capable of delicate manipulation as well as powerful gripping actions. The arrangement of its 27 small bones, moved by 37 skeletal muscles that are connected to the bones by tendons, allows a wide range of movements. Our ability to bring the tips of our thumbs and fingers together, combined with the extraordinary sensitivity of our fingertips due to their rich supply of nerve endings, makes our hands uniquely dextrous.

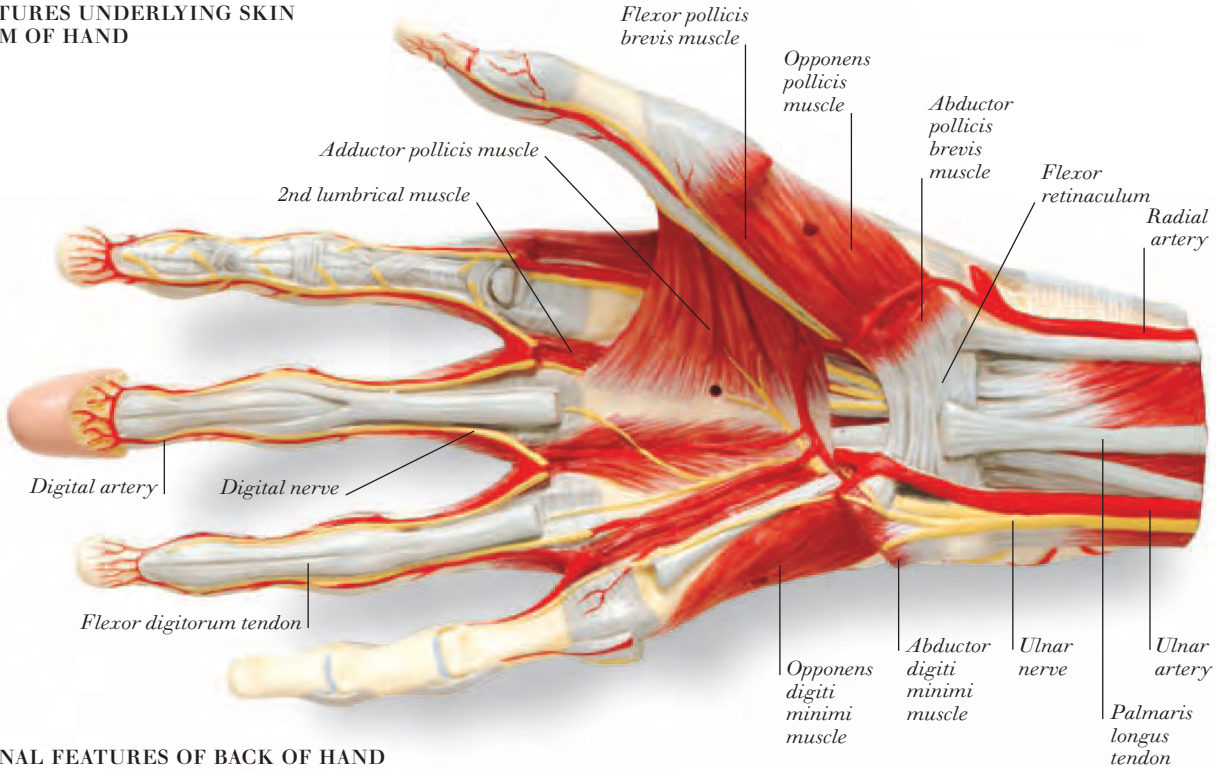
X-RAY OF LEFT HAND OF A YOUNG CHILD

Areas of cartilage in the wrist and at the ends of the finger bones are the sites of growth and have still to ossify.

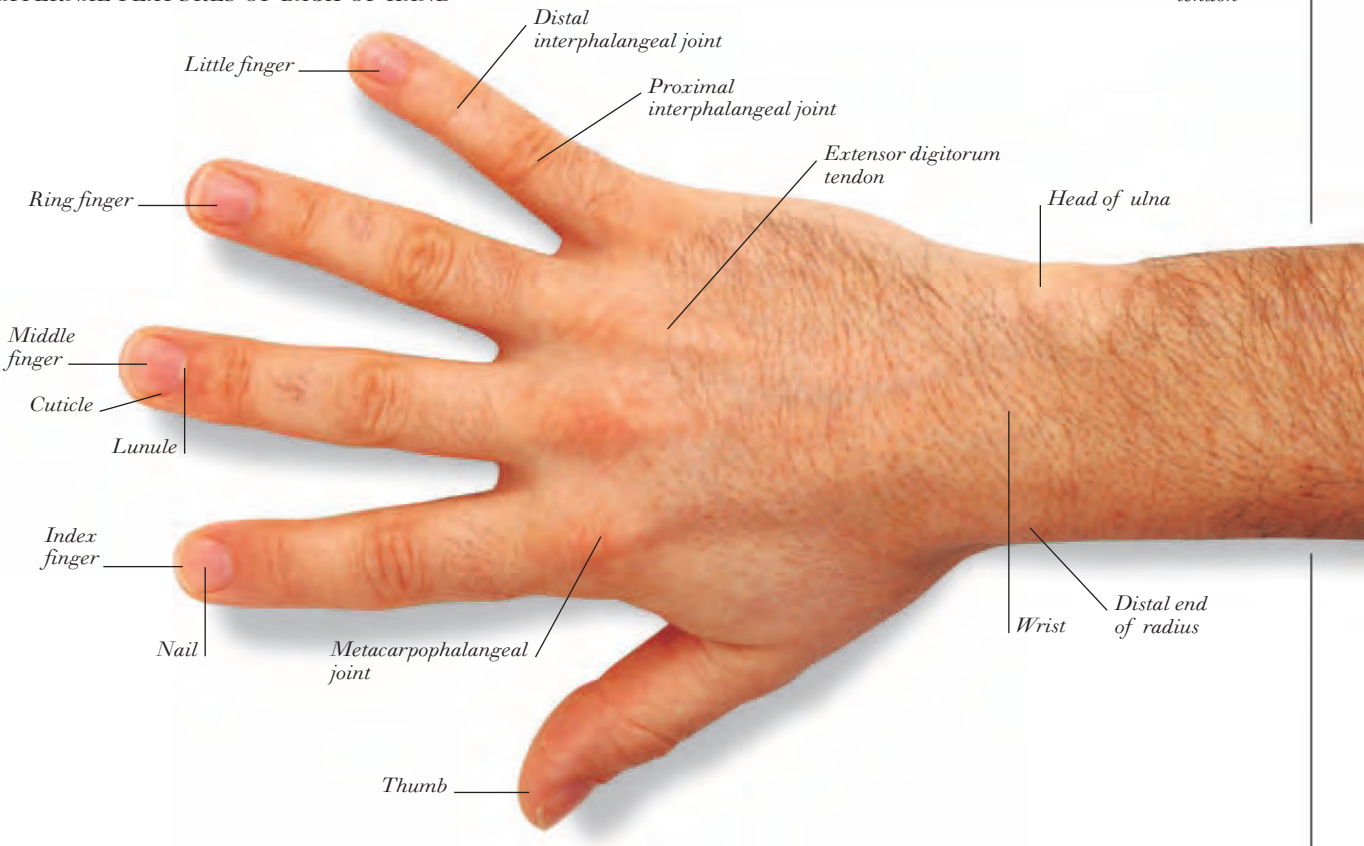
BONES OF HAND



STRUCTURES UNDERLYING SKIN OF PALM OF HAND



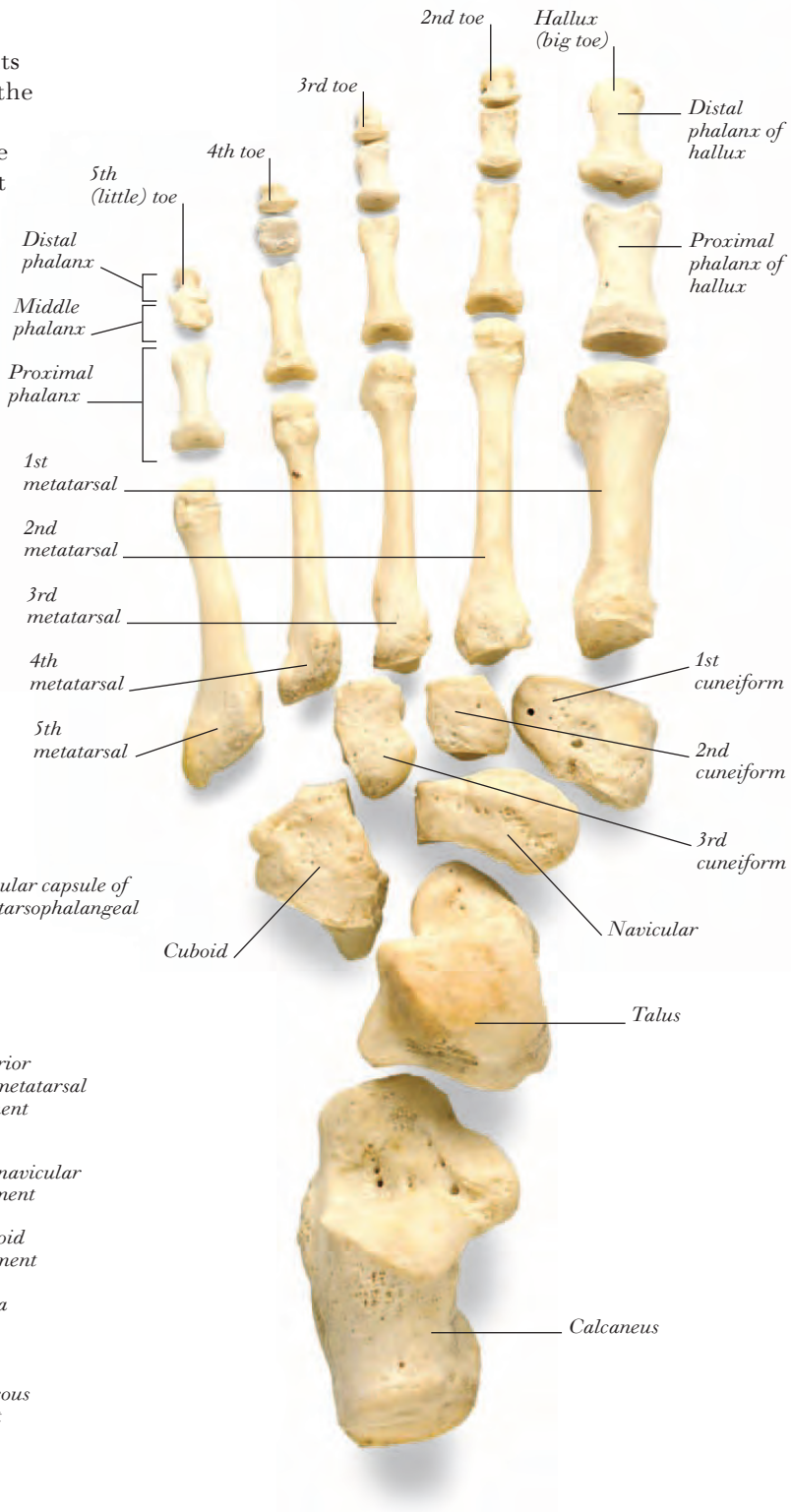
EXTERNAL FEATURES OF BACK OF HAND



Feet

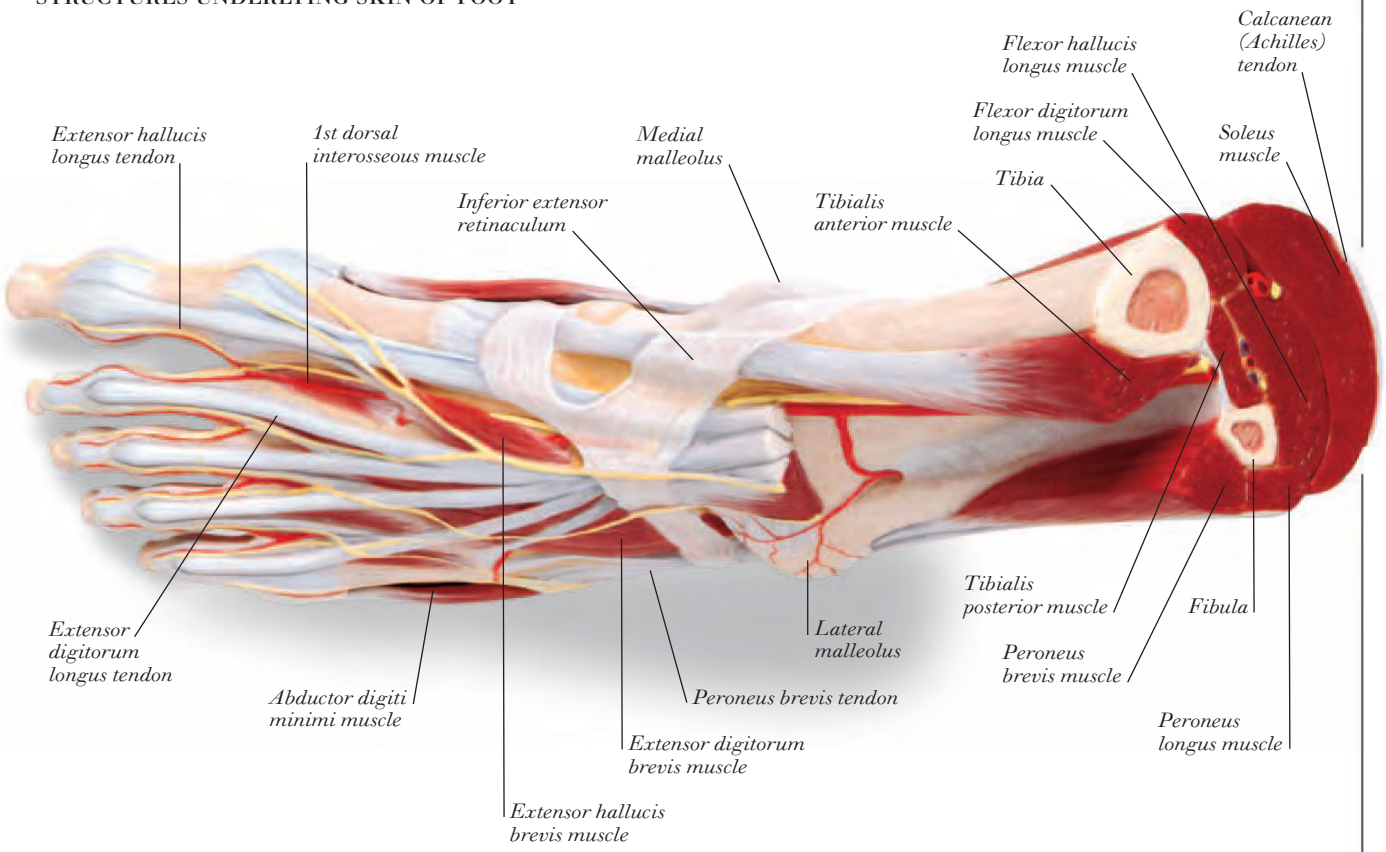
THE FEET AND TOES are essential elements in body movement. They bear and propel the weight of the body during walking and running, and also help to maintain balance during changes of body position. Each foot has 26 bones, more than 100 ligaments, and 33 muscles, some of which are attached to the lower leg. The heel pad and the arch of the foot act as shock absorbers, providing a cushion against the jolts that occur with every step.

BONES OF FOOT

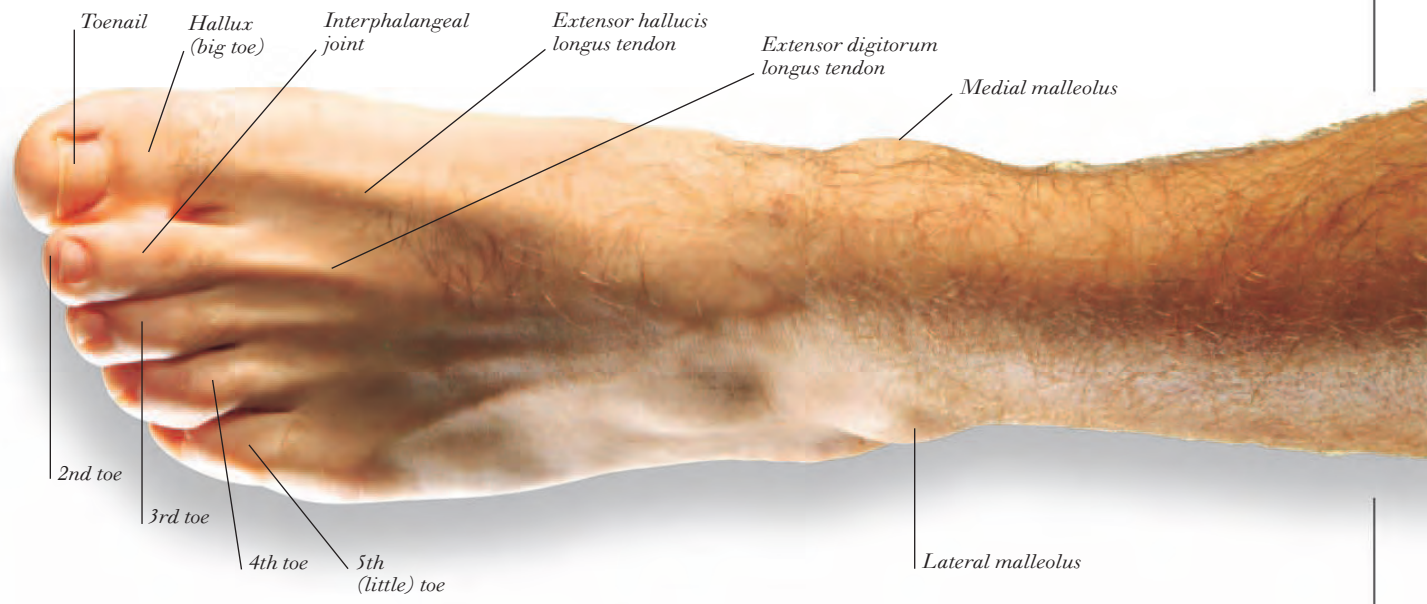


LIGAMENTS OF FOOT

STRUCTURES UNDERLYING SKIN OF FOOT



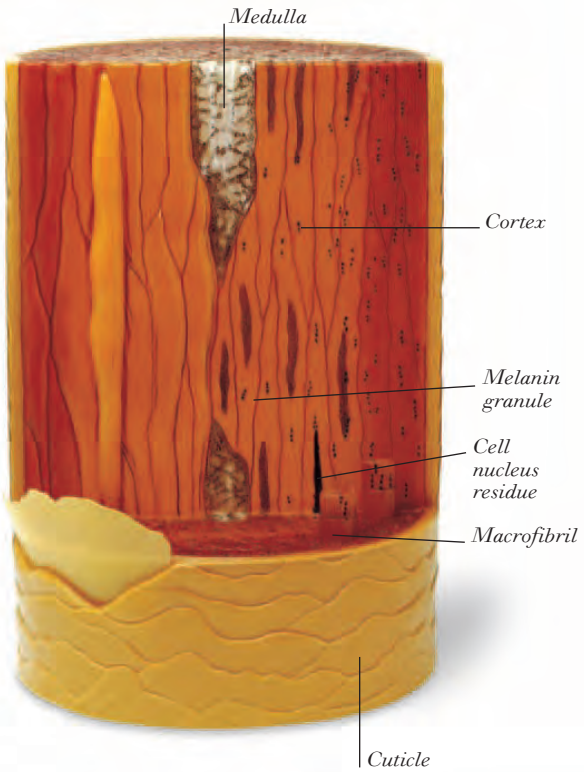
EXTERNAL FEATURES OF FOOT



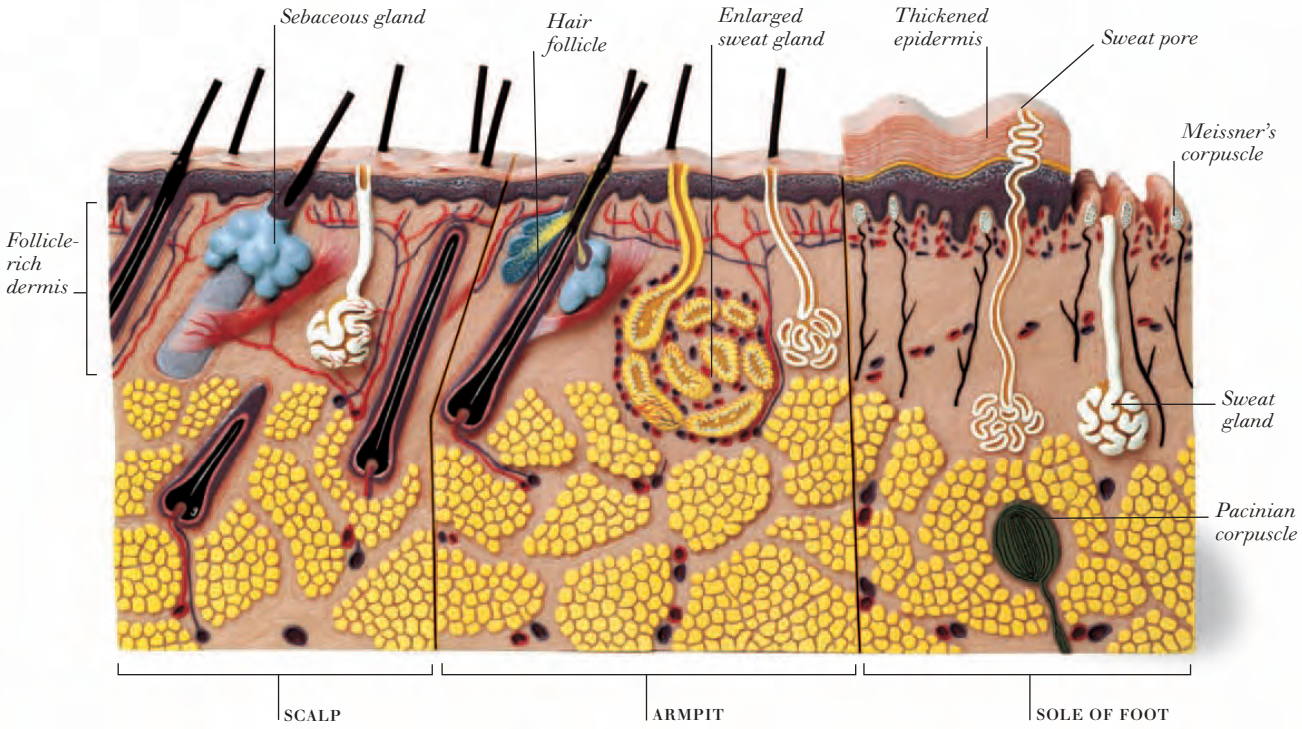
Skin and hair

SKIN IS THE BODY'S LARGEST ORGAN, a waterproof barrier that protects the internal organs against infection, injury, and harmful sun rays. The skin is also an important sensory organ and helps to control body temperature. The outer layer of the skin, known as the epidermis, is coated with keratin, a tough, horny protein that is also the chief constituent of hair and nails. Dead cells are shed from the skin's surface and are replaced by new cells from the base of the epidermis, the region that also produces the skin pigment, melanin. The dermis contains most of the skin's living structures, and includes nerve endings, blood vessels, elastic fibers, sweat glands that cool the skin, and sebaceous glands that produce oil to keep the skin supple. Beneath the dermis lies the subcutaneous tissue (hypodermis), which is rich in fat and blood vessels. Hair shafts grow from hair follicles situated in the dermis and subcutaneous tissue. Hair grows on every part of the skin apart from the palms of the hands and soles of the feet.

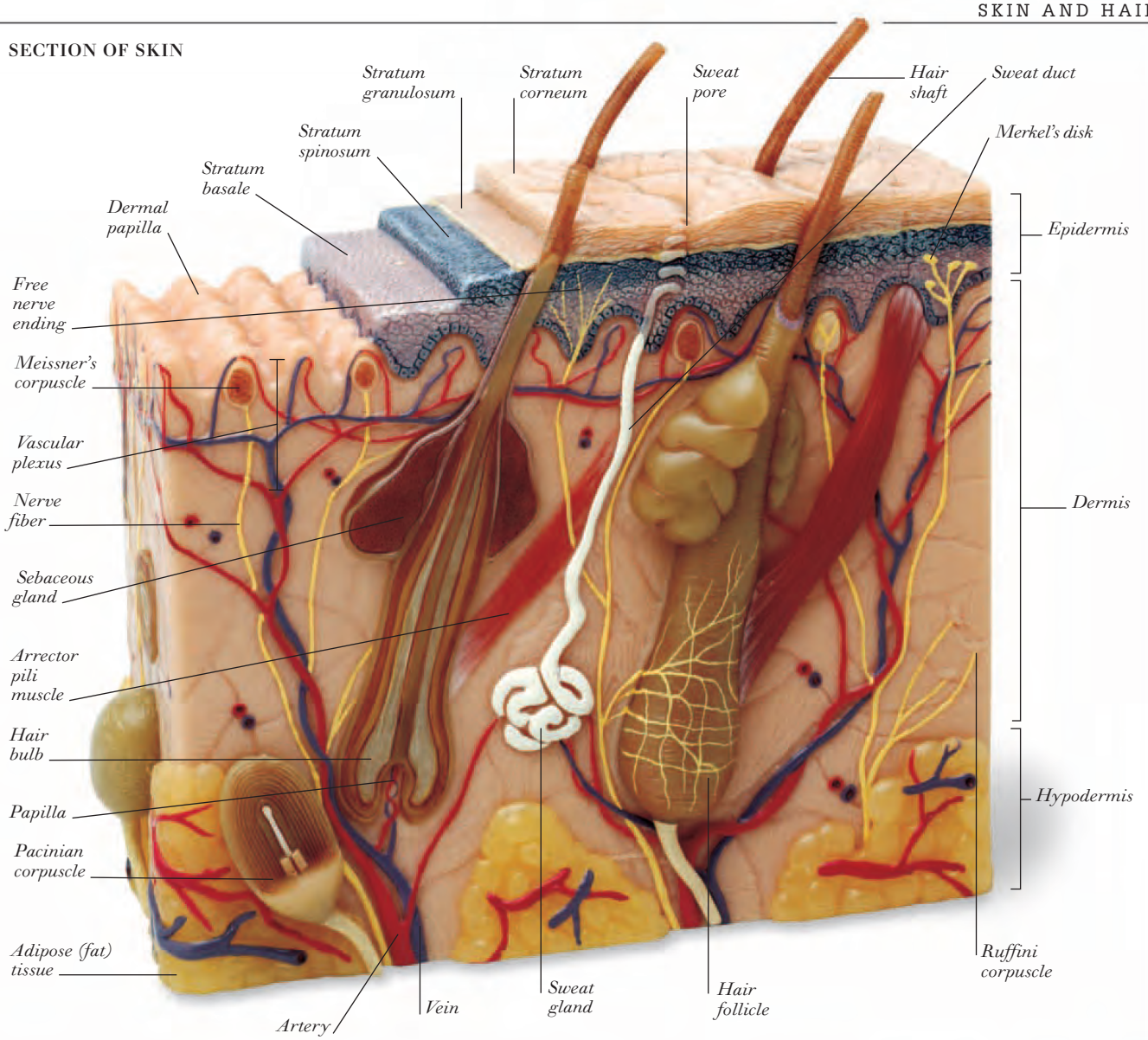
SECTION OF HAIR



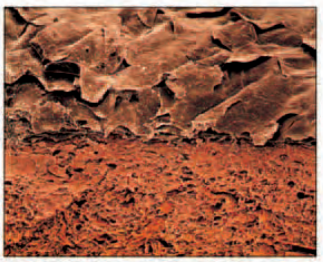
SECTIONS OF DIFFERENT TYPES OF SKIN



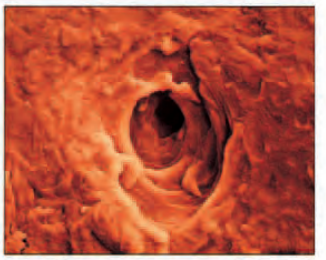
SECTION OF SKIN



PHOTOMICROGRAPHS OF SKIN AND HAIR

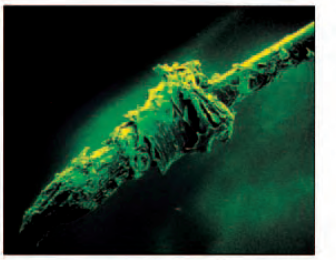


SECTION OF SKIN
The flaky cells at the skin's surface are shed continuously.



SWEAT PORE
This allows loss of fluid as part of temperature control.

SKIN HAIR
Two hairs pushing through the outer layer of skin.

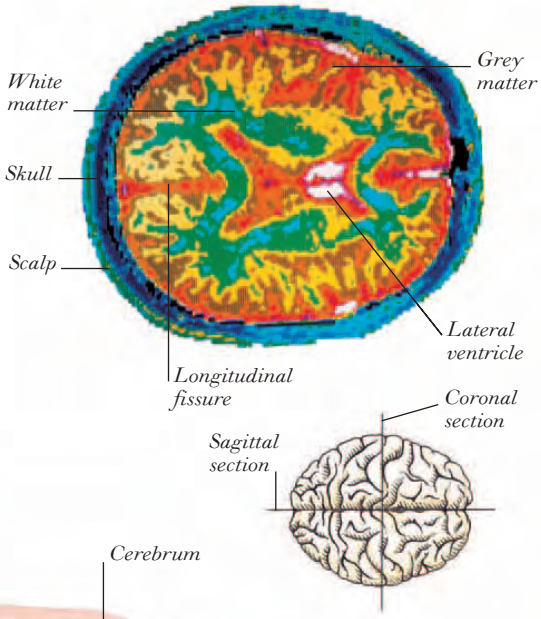


HEAD HAIR
The root and part of the shaft of a hair from the scalp.

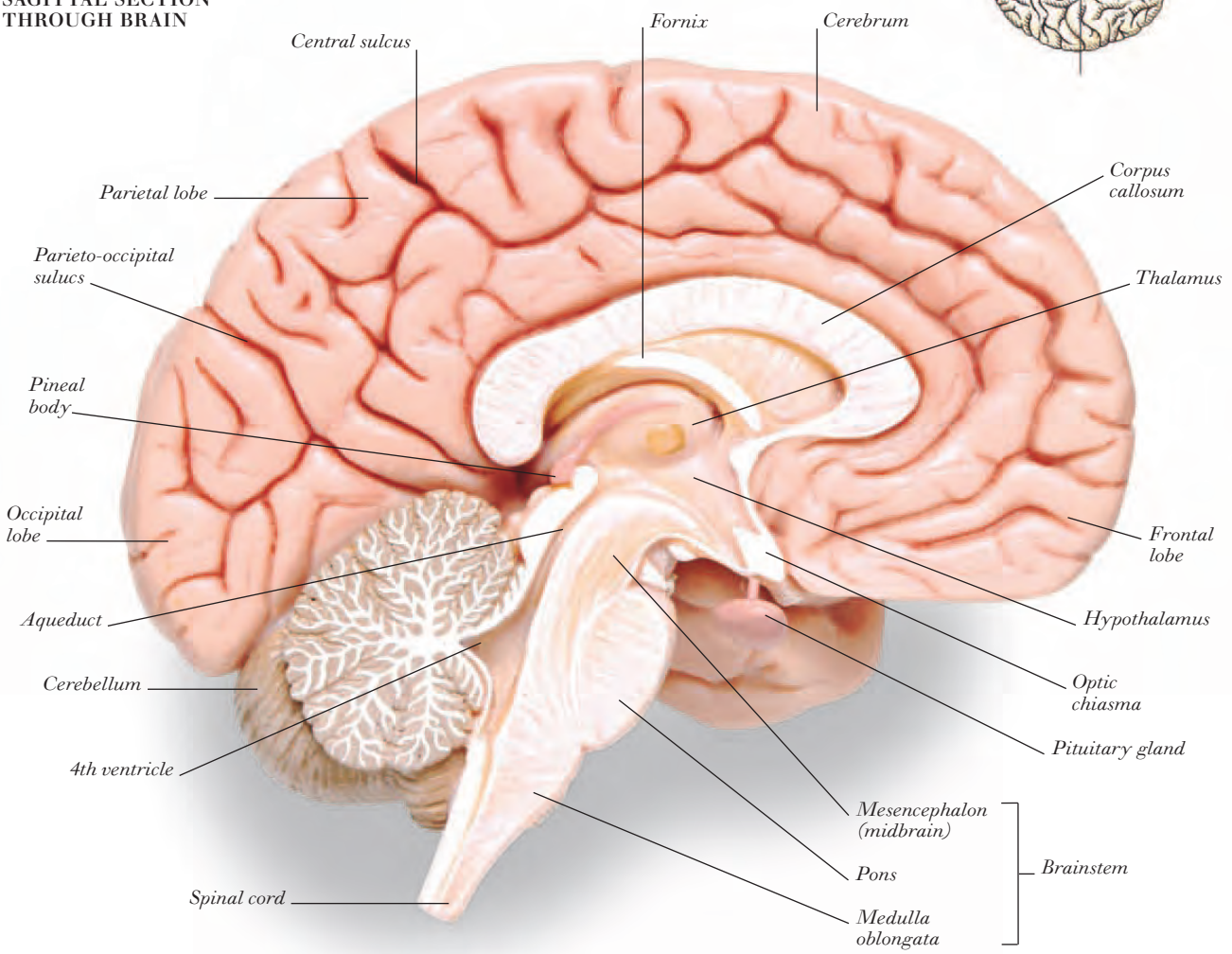
Brain

THE BRAIN IS THE MAJOR ORGAN of the central nervous system and the control center for all the body's voluntary and involuntary activities. It is also responsible for the complexities of thought, memory, emotion, and language. In adults, this complex organ is a mere 3 lb (1.4 kg) in weight, containing over 10 billion nerve cells. Three distinct regions can easily be seen—the brainstem, the cerebellum, and the large cerebrum. The brainstem controls vital body functions, such as breathing and digestion. The cerebellum's main functions are the maintenance of posture and the coordination of body movements. The cerebrum, which consists of the right and left cerebral hemispheres joined by the corpus callosum, is the site of most conscious and intelligent activities.

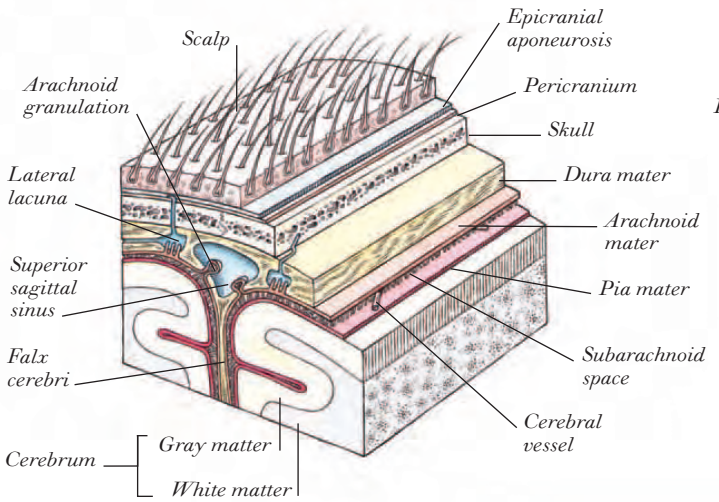
MRI SCAN OF TRANSVERSE SECTION THROUGH BRAIN



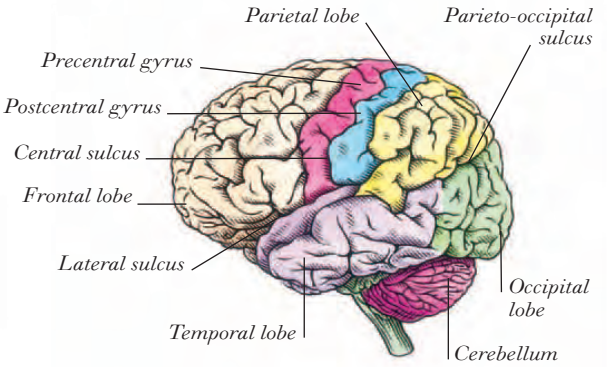
SAGITTAL SECTION THROUGH BRAIN



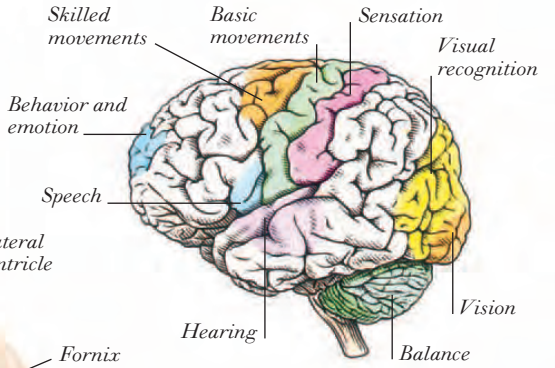
SECTION THROUGH SKULL AND BRAIN



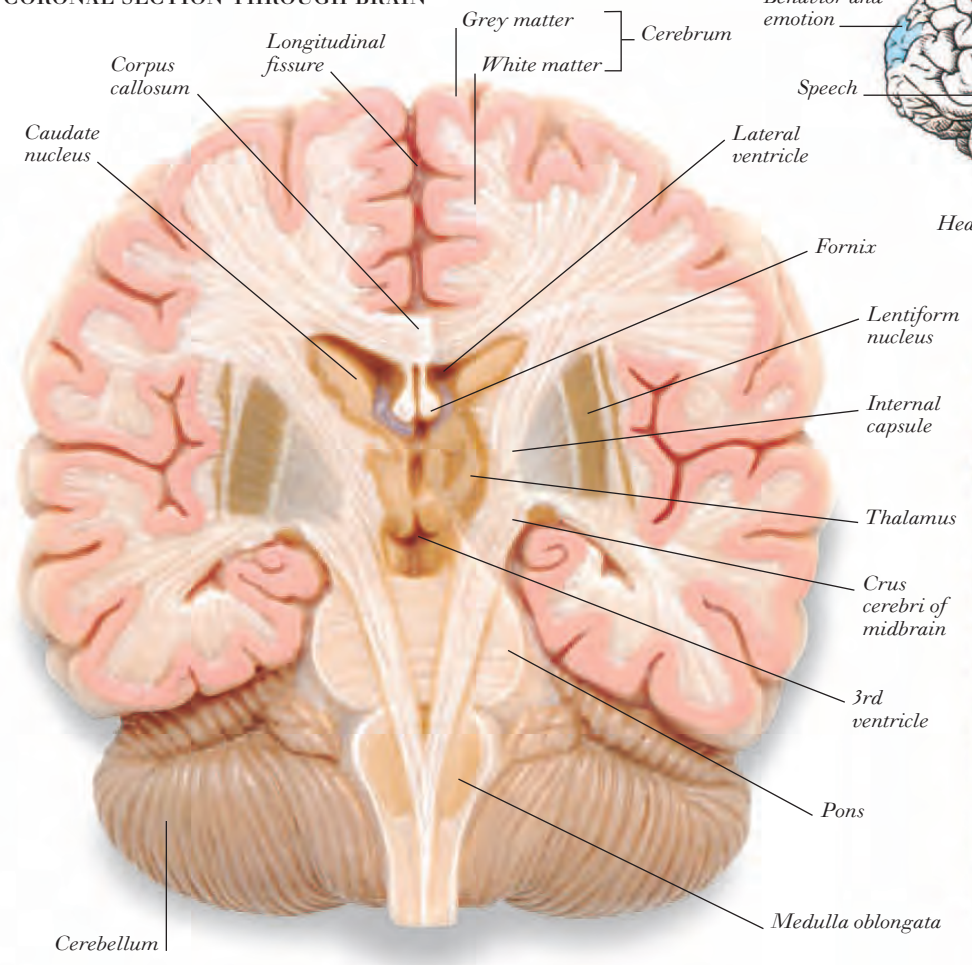
EXTERNAL ANATOMY OF BRAIN



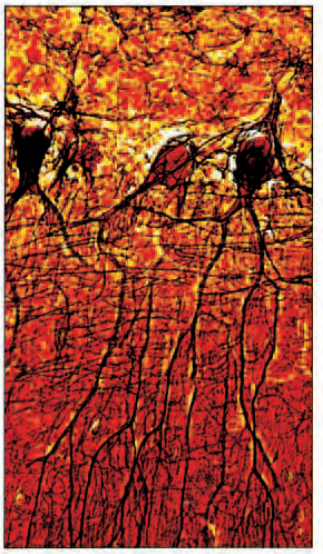
SPECIFIC ROLES OF AREAS OF CEREBRUM



CORONAL SECTION THROUGH BRAIN

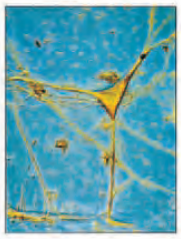


NERVE CELLS IN BRAIN



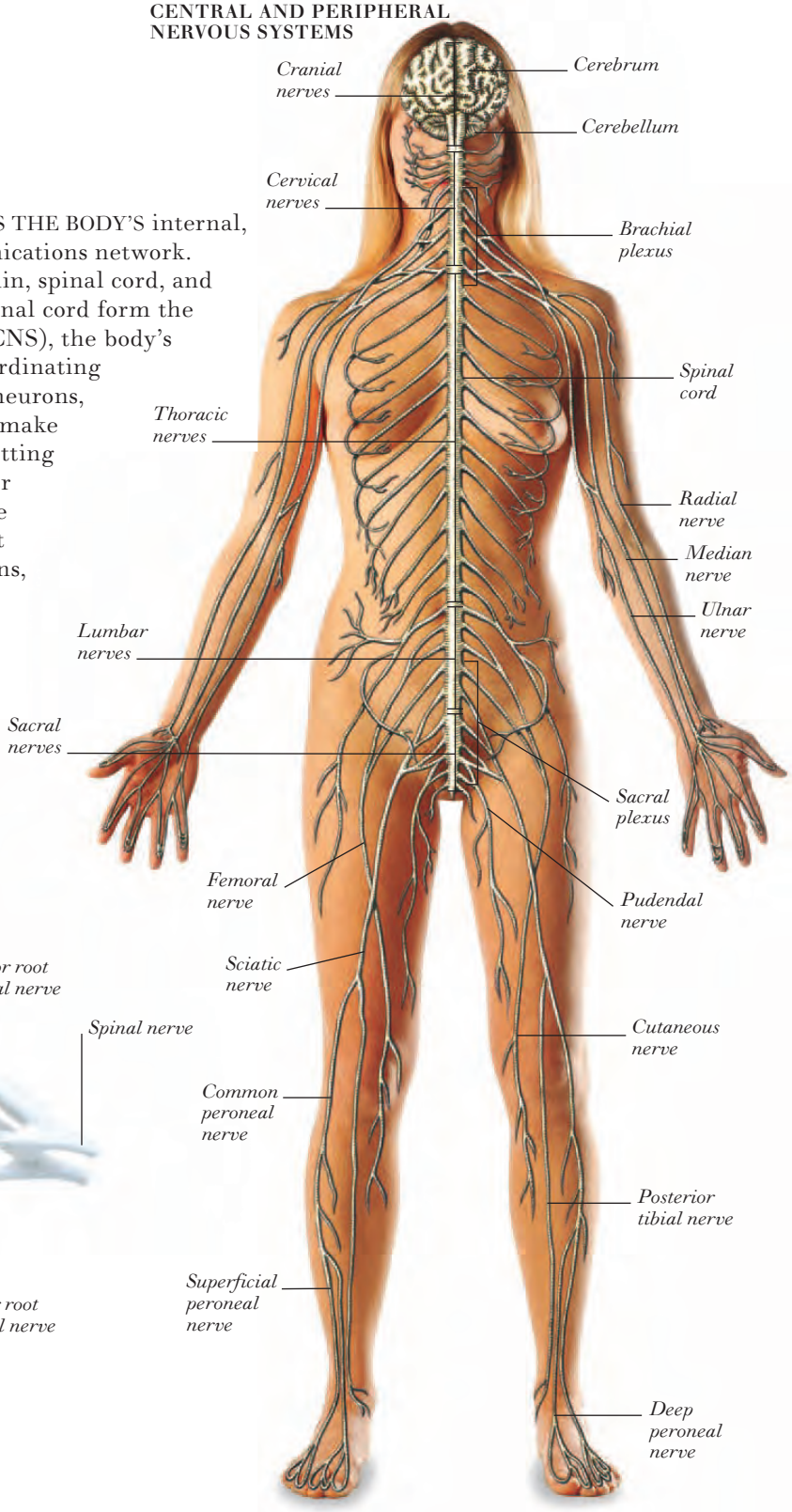
The dark cells are Purkinje's cells, which are among the largest nerve cells in the body.

Nervous system

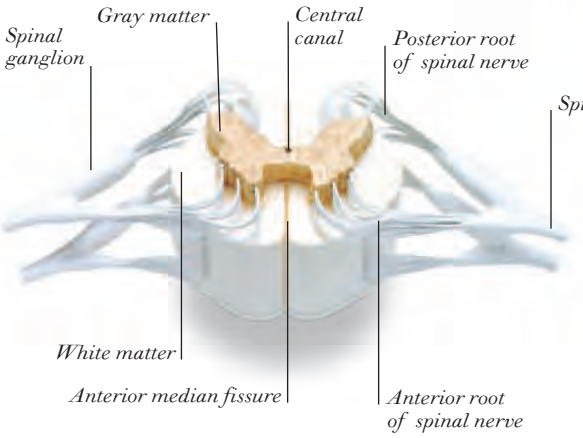


THE NERVOUS SYSTEM IS THE BODY'S internal, electrochemical, communications network. Its main parts are the brain, spinal cord, and nerves. The brain and spinal cord form the central nervous system (CNS), the body's chief controlling and coordinating centers. Billions of long neurons, many grouped as nerves, make up the peripheral nervous system, transmitting nerve impulses between the CNS and other regions of the body. Each neuron has three parts: a cell body, branching dendrites that receive chemical signals from other neurons, and a tubelike axon that conveys these signals as electrical impulses.

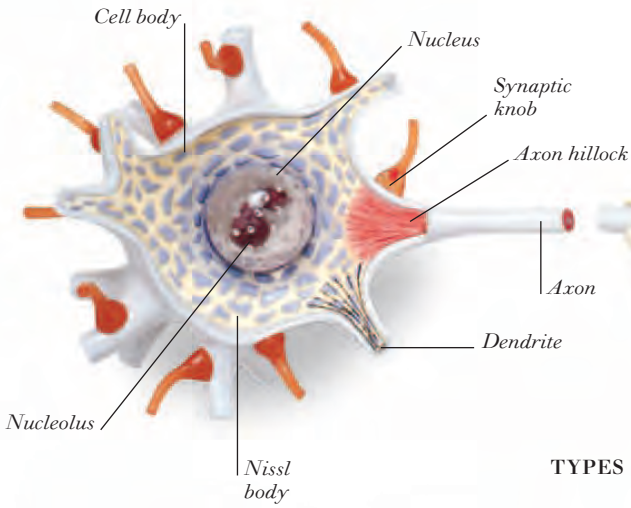
CENTRAL AND PERIPHERAL NERVOUS SYSTEMS

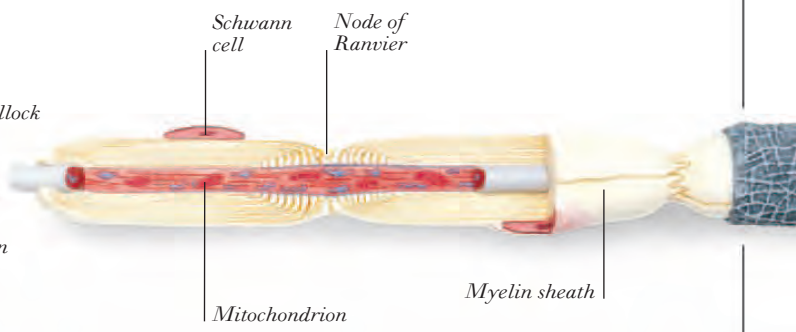


SECTION THROUGH SPINAL CORD

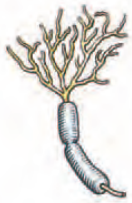


STRUCTURE OF A MOTOR NEURON





TYPES OF NERVE ENDING



FREE NERVE ENDING

MEISSNER'S CORPUSCLE

MERKEL'S DISK

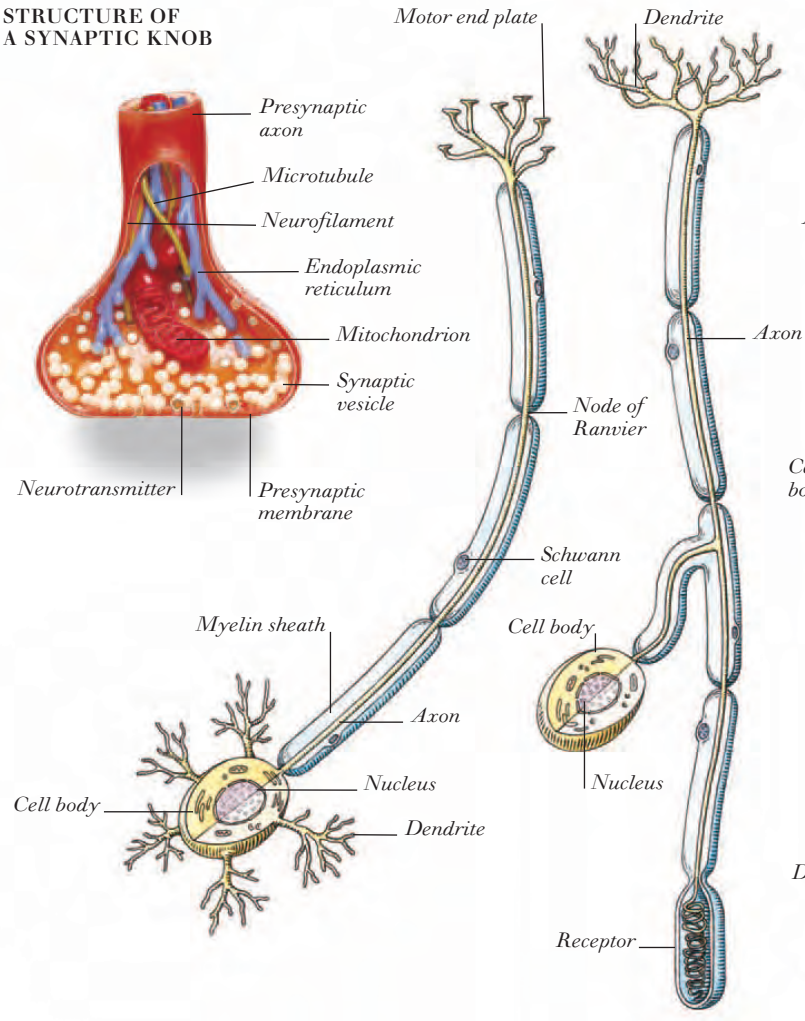
RUFFINI CORPUSCLE

PACINIAN CORPUSCLE

STRUCTURE OF A SYNAPTIC KNOB

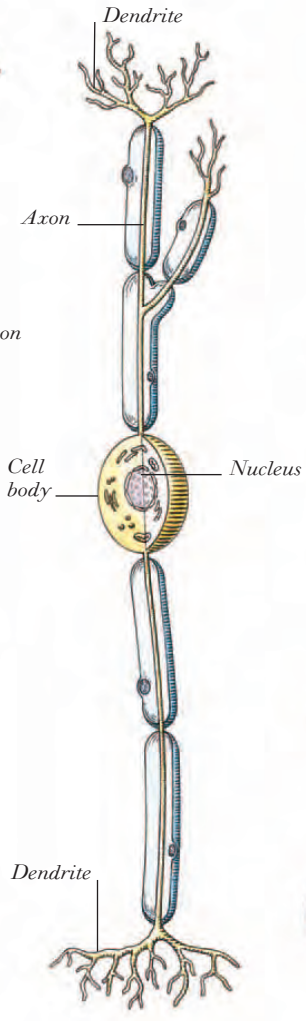
TYPES OF NEURON

MULTIPOLAR



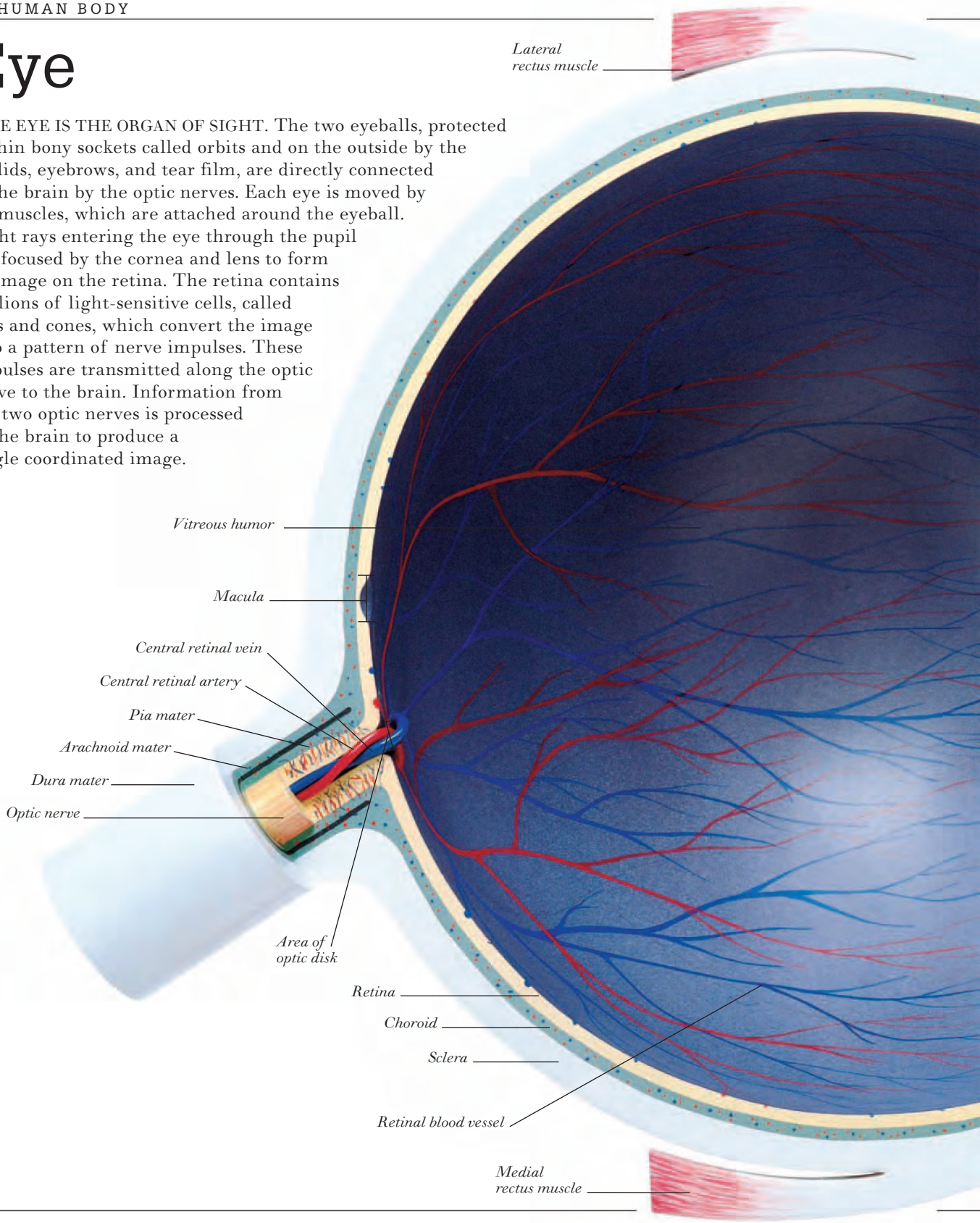
UNIPOLAR

BIPOLAR

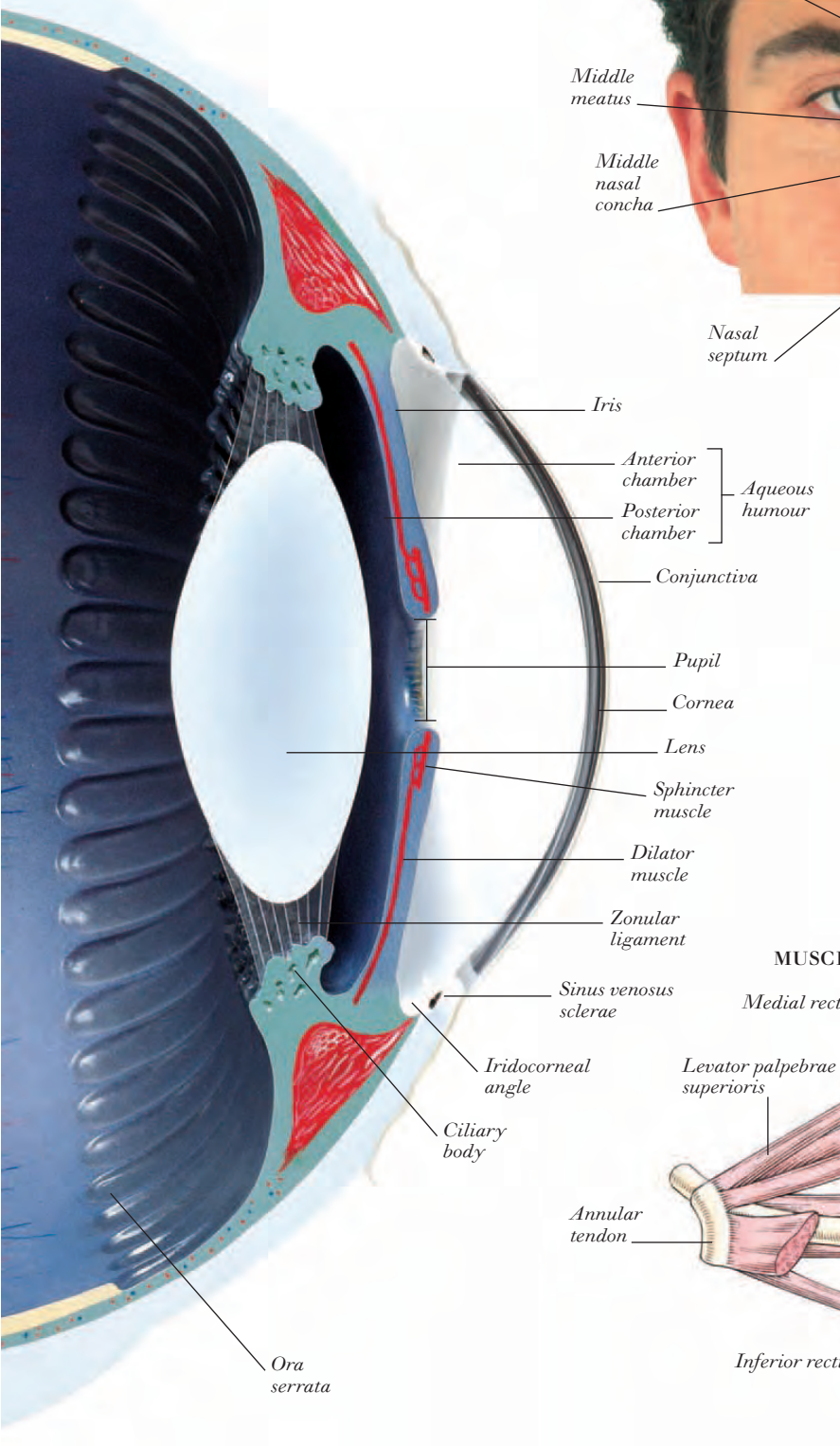


Eye

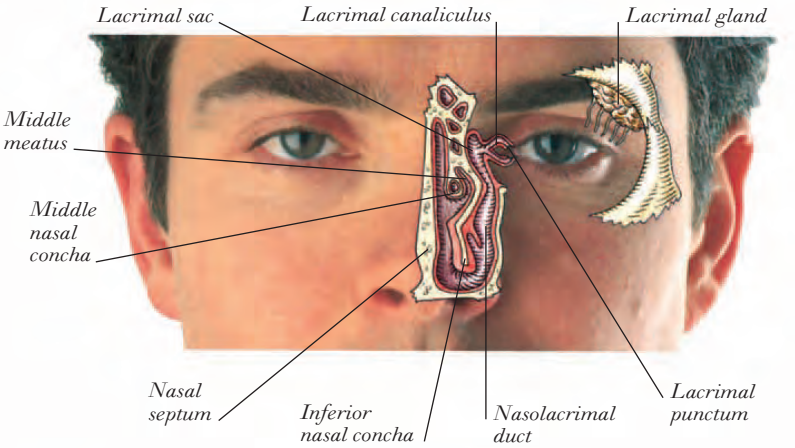
THE EYE IS THE ORGAN OF SIGHT. The two eyeballs, protected within bony sockets called orbits and on the outside by the eyelids, eyebrows, and tear film, are directly connected to the brain by the optic nerves. Each eye is moved by six muscles, which are attached around the eyeball. Light rays entering the eye through the pupil are focused by the cornea and lens to form an image on the retina. The retina contains millions of light-sensitive cells, called rods and cones, which convert the image into a pattern of nerve impulses. These impulses are transmitted along the optic nerve to the brain. Information from the two optic nerves is processed in the brain to produce a single coordinated image.



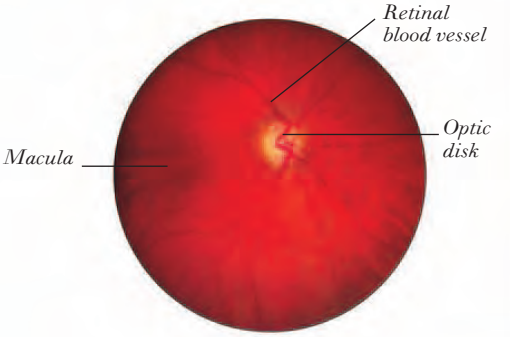
SECTION THROUGH LEFT EYE



LACRIMAL (TEAR-PRODUCING) APPARATUS

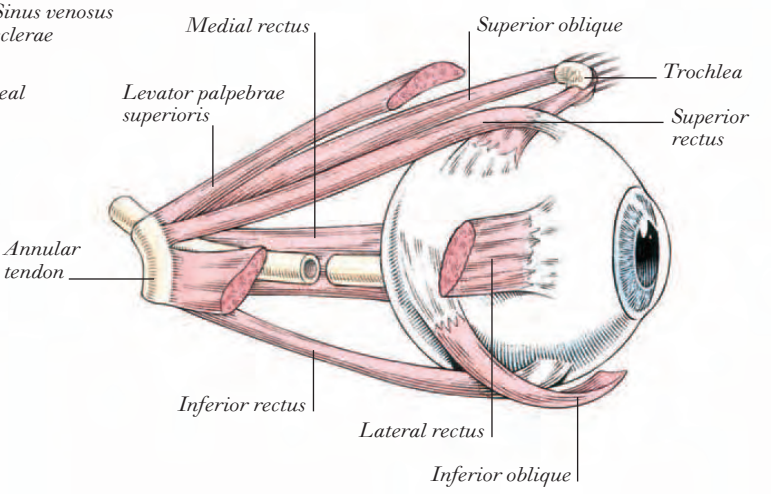


OPHTHALMOSCOPIC VIEW OF RETINA



The blind spot, where the optic nerve leaves the eye, can be clearly seen as a light circular area toward the center of the image.

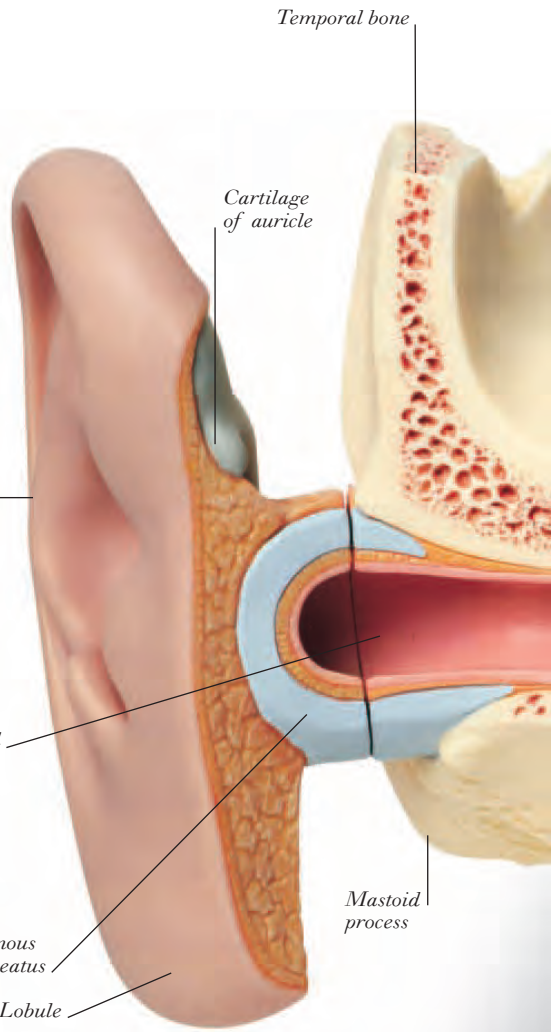
MUSCLES SURROUNDING RIGHT EYE



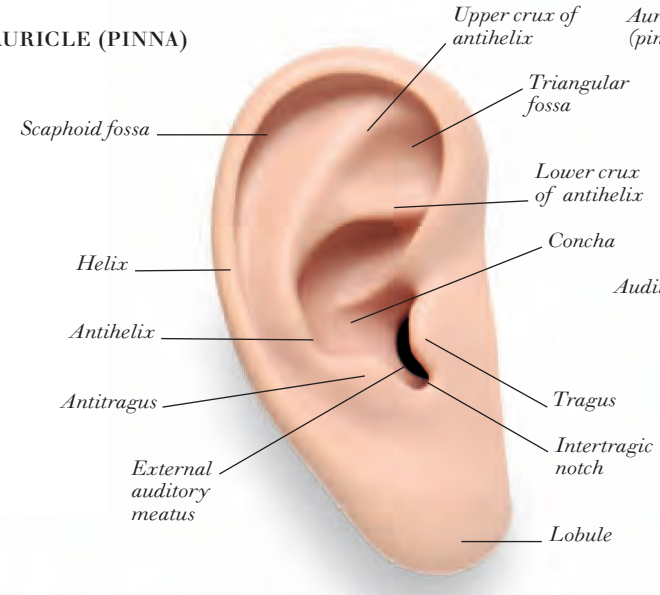
Ear

THE EAR IS THE ORGAN OF HEARING AND BALANCE. The outer ear consists of a flap called the auricle or pinna and the auditory canal. The main functional parts-the middle and inner ears-are enclosed within the skull. The middle ear consists of three tiny bones, known as auditory ossicles, and the eustachian tube, which links the ear to the back of the nose. The inner ear consists of the spiral-shaped cochlea, and also the semicircular canals and the vestibule, which are the organs of balance. Sound waves entering the ear travel through the auditory canal to the tympanic membrane (eardrum), where they are converted to vibrations that are transmitted via the ossicles to the cochlea. Here, the vibrations are converted by millions of microscopic hairs into electrical nerve signals to be interpreted by the brain.

STRUCTURE OF EAR



RIGHT AURICLE (PINNA)

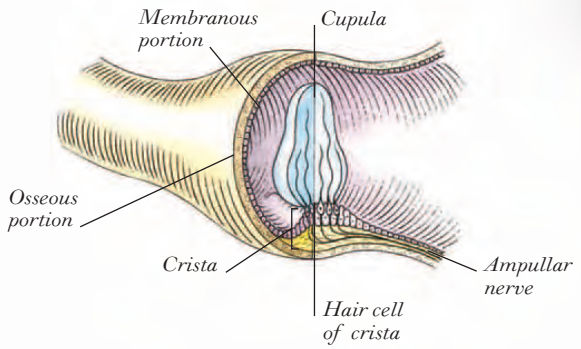


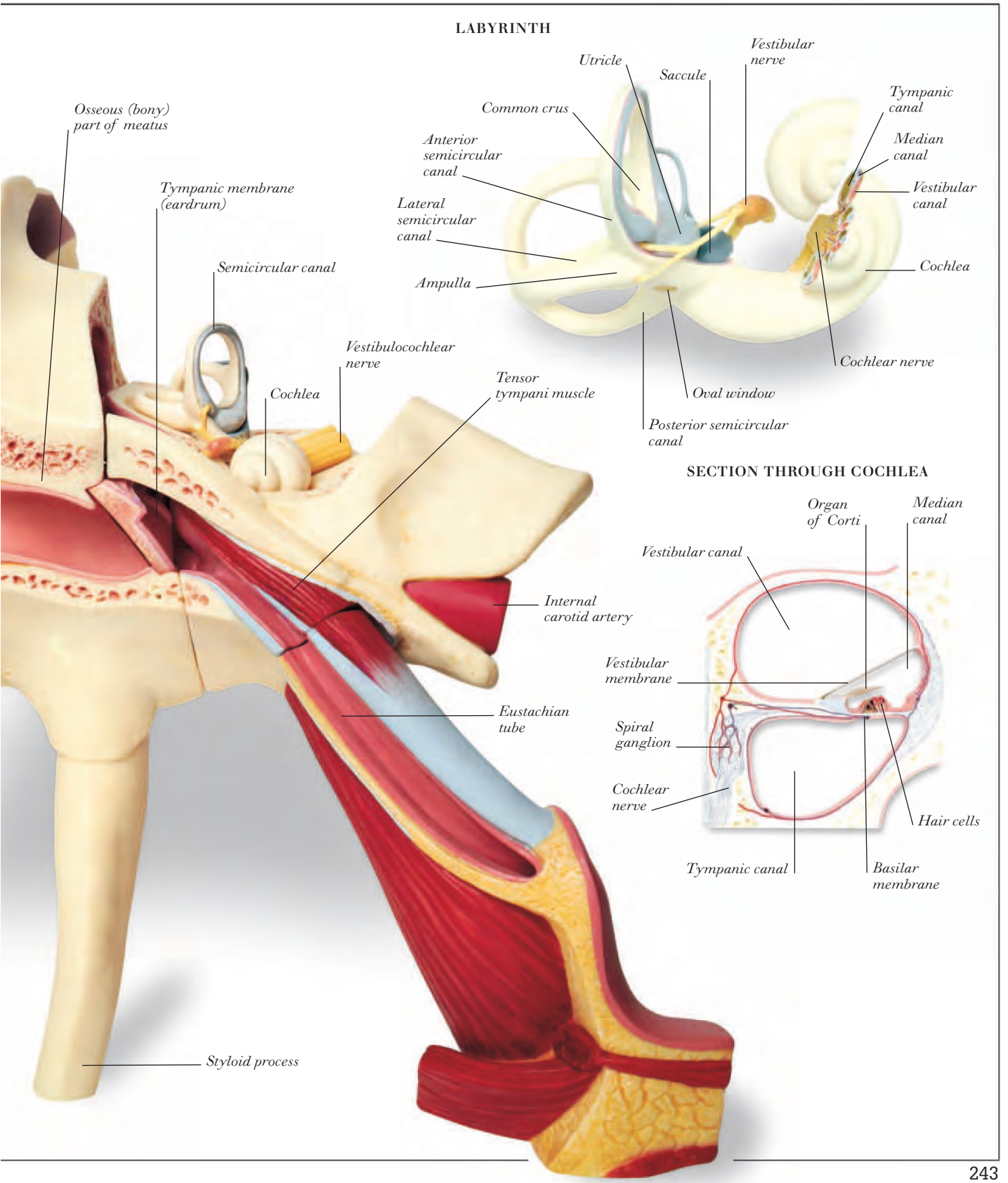
OSSICLES OF MIDDLE EAR

MALLEUS (HAMMER) INCUS (ANVIL) STAPES (STIRRUP)

These three tiny bones connect to form a bridge between the tympanic membrane and the oval window. With a system of membranes they convey sound vibrations to the inner ear.

INTERNAL STRUCTURE OF AMPULLA

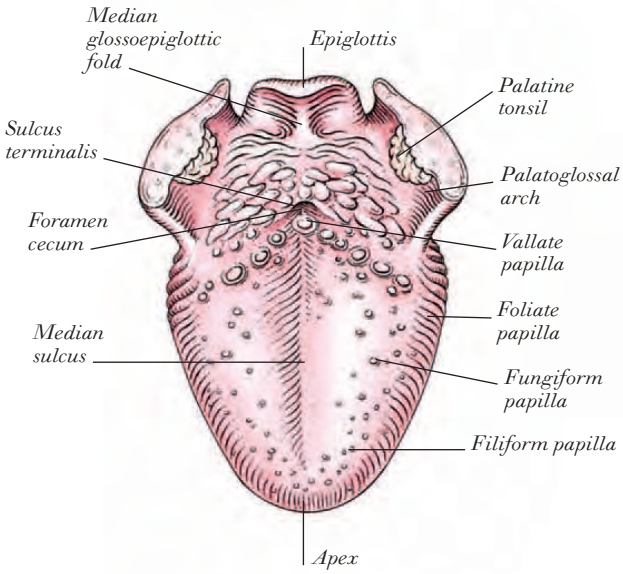



LABYRINTH
Utricle
Saccule
Vestibular nerve
Common crus
Tympanic canal
Anterior semicircular canal
Median canal
Lateral semicircular canal
Vestibular canal
Ampulla
Cochlea
Cochlear nerve
Oval window
Posterior semicircular canal
Osseous (bony) part of meatus
Tympanic membrane (eardrum)
Semicircular canal
Vestibulocochlear nerve
Cochlea
Tensor tympani muscle
Internal carotid artery
Eustachian tube
Styloid process
SECTION THROUGH COCHLEA
Organ of Corti
Median canal
Vestibular canal
Vestibular membrane
Spiral ganglion
Cochlear nerve
Hair cells
Tympanic canal
Basilar membrane

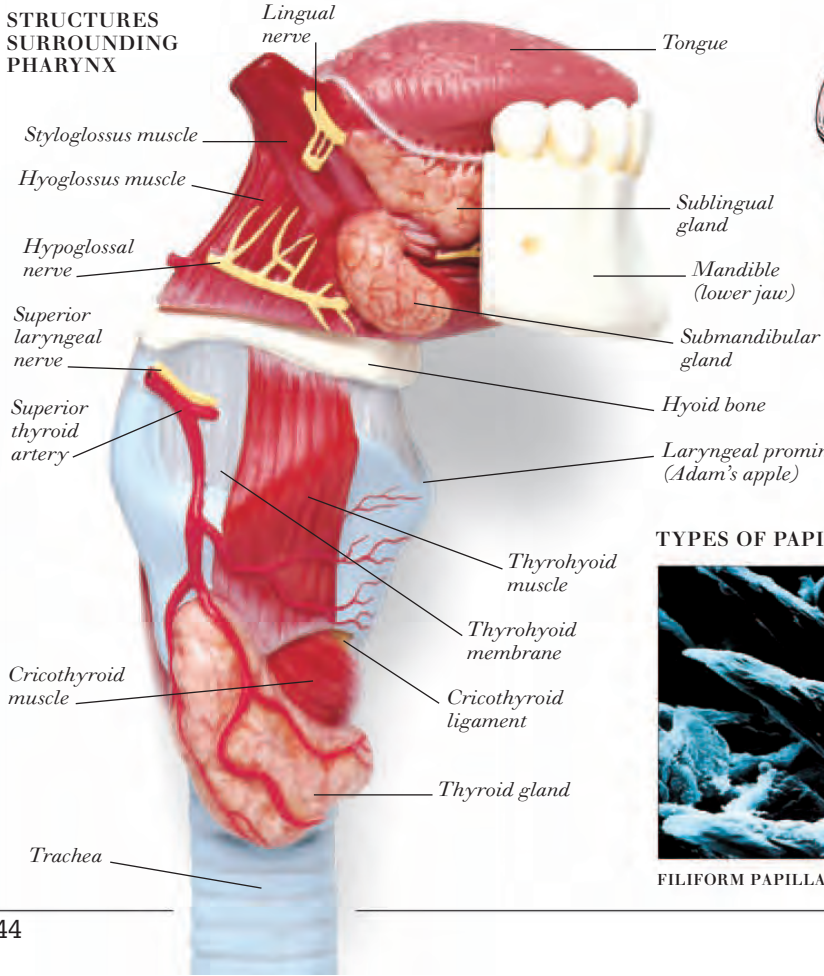
Nose, mouth, and throat

WITH EVERY BREATH, air passes through the nasal cavity down the pharynx (throat), larynx ("voice box"), and trachea (windpipe) to the lungs. The nasal cavity warms and moistens air, and the tiny layers in its lining protect the airway against damage by foreign bodies. During swallowing, the tongue moves up and back, the larynx rises, the epiglottis closes off the entrance to the trachea, and the soft palate separates the nasal cavity from the pharynx. Saliva, secreted from three pairs of salivary glands, lubricates food to make swallowing easier; it also begins the chemical breakdown of food, and helps to produce taste. The senses of taste and smell are closely linked. Both depend on the detection of dissolved molecules by sensory receptors in the olfactory nerve endings of the nose and in the taste buds of the tongue.

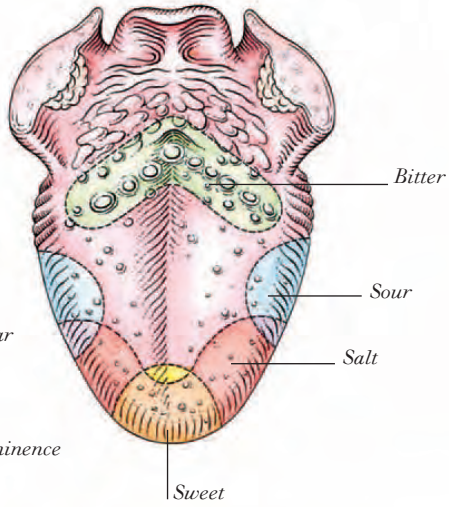
STRUCTURE OF TONGUE



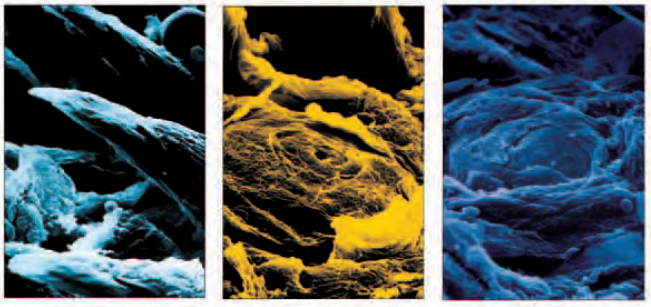
STRUCTURES SURROUNDING PHARYNX



TASTE AREAS ON TONGUE

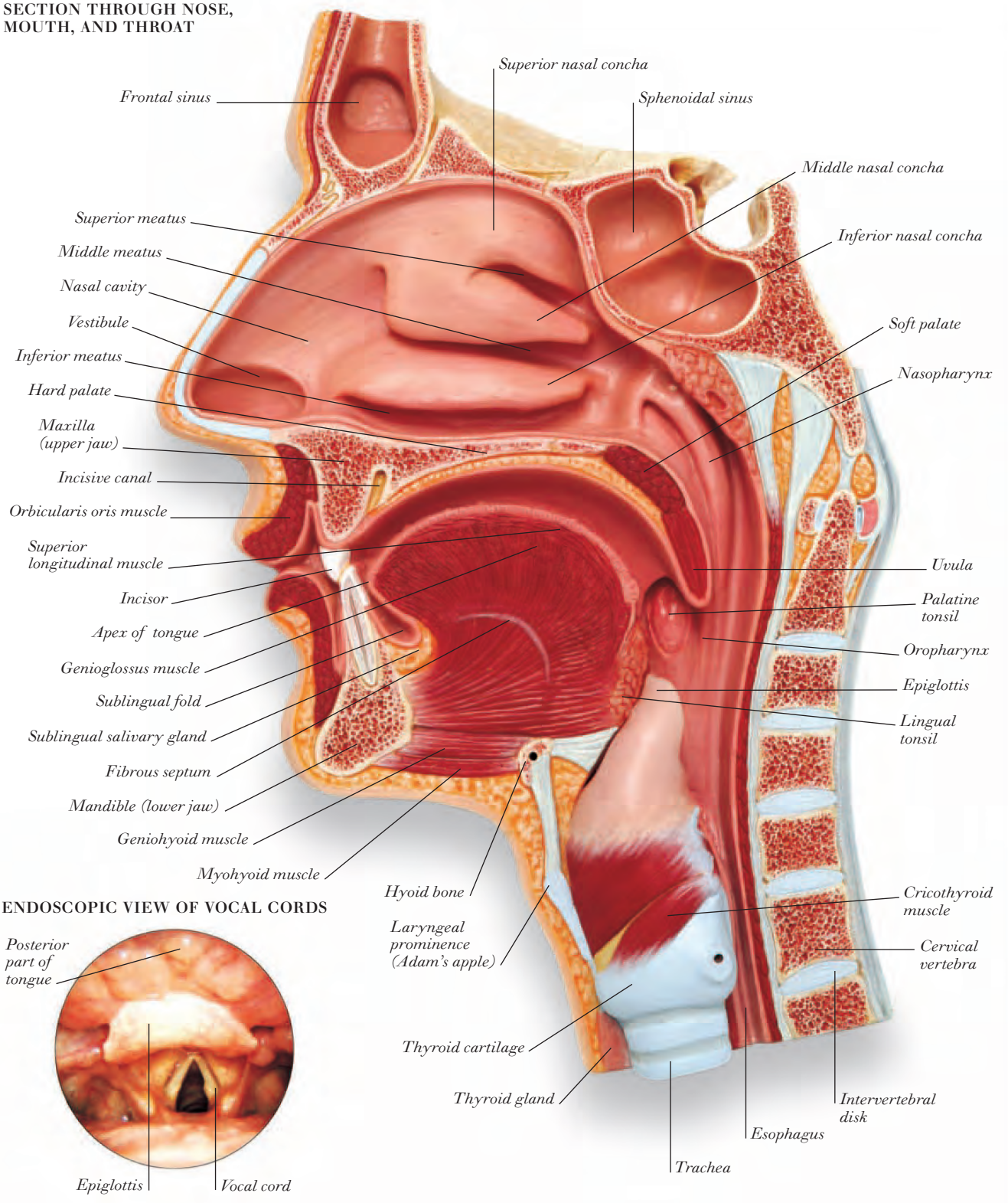


TYPES OF PAPILLAE



FILIFORM PAPILLAE | FUNGIFORM PAPILLAE | VALLATE PAPILLAE

SECTION THROUGH NOSE, MOUTH, AND THROAT

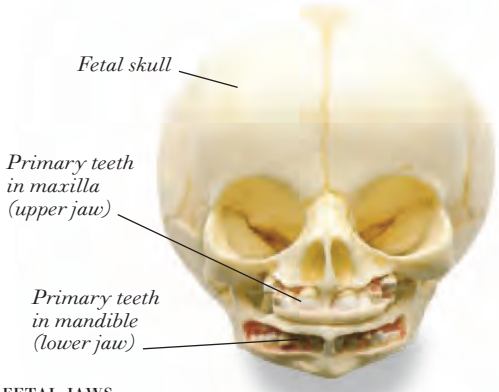


ENDOSCOPIC VIEW OF VOCAL CORDS

Teeth

THE 20 PRIMARY TEETH (also called deciduous or baby teeth) usually begin to erupt when a baby is about six months old. They start to be replaced by the permanent teeth when the child is about six years old. By the age of 20, most adults have a full set of 32 teeth although the third molars (commonly called wisdom teeth) may never erupt. While teeth help people to speak clearly and give shape to the face, their main function is the chewing of food. Incisors and canines shear and tear the food into pieces; premolars and molars crush and grind it further. Although tooth enamel is the hardest substance in the body, it tends to be eroded and destroyed by acid produced in the mouth during the breakdown of food.

DEVELOPMENT OF TEETH IN A FETUS



FETAL JAWS
By the sixth week of embryonic development areas of thickening occur in each jaw; these areas give rise to tooth buds. By the time the fetus is six months old, enamel has formed on the tooth buds.

DEVELOPMENT OF JAW AND TEETH

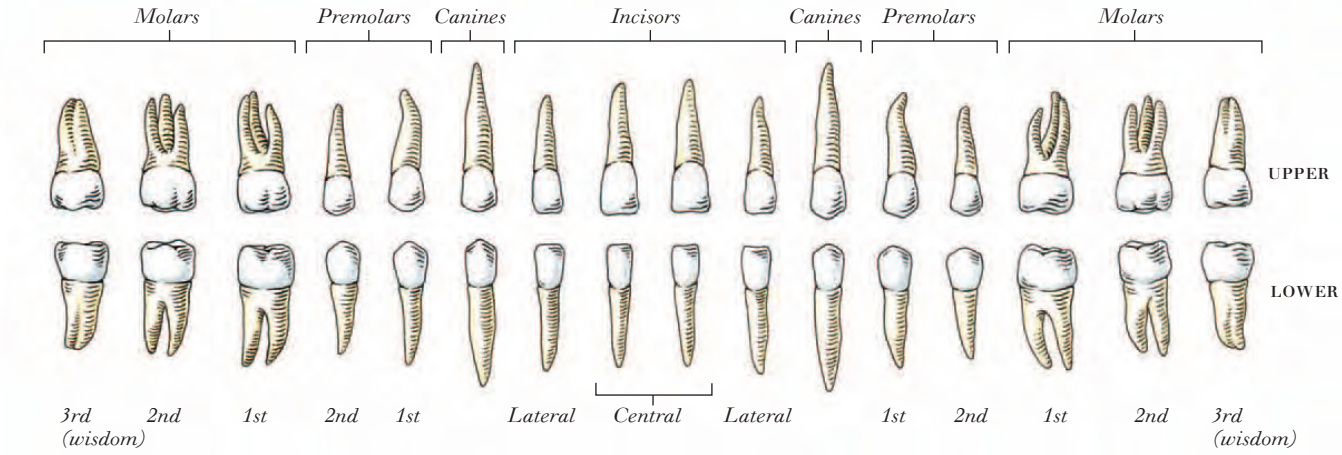
A NEWBORN BABY'S JAWS
The primary teeth can be seen developing in the jaw bones; they begin to erupt around the age of six months.

A FIVE-YEAR-OLD CHILD'S TEETH
There is a full set of 20 erupted primary teeth; the permanent teeth can be seen developing in the upper and lower jaws.

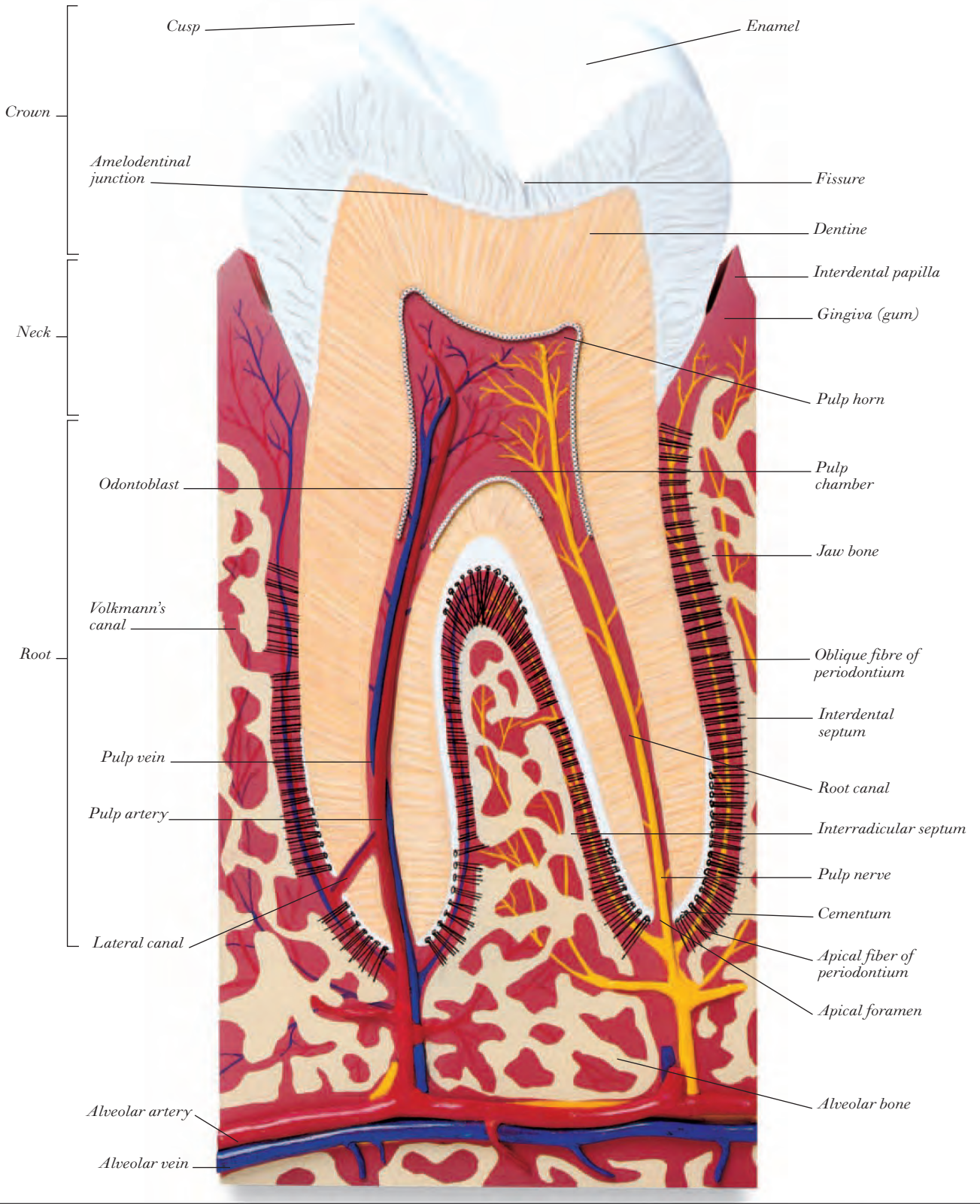
A NINE-YEAR-OLD CHILD'S TEETH
Most of the teeth are primary teeth but the permanent incisors and first molars have now emerged.

AN ADULT'S TEETH
By the age of 20, the full set of 32 permanent teeth (including the wisdom teeth) should be in position.

THE PERMANENT TEETH

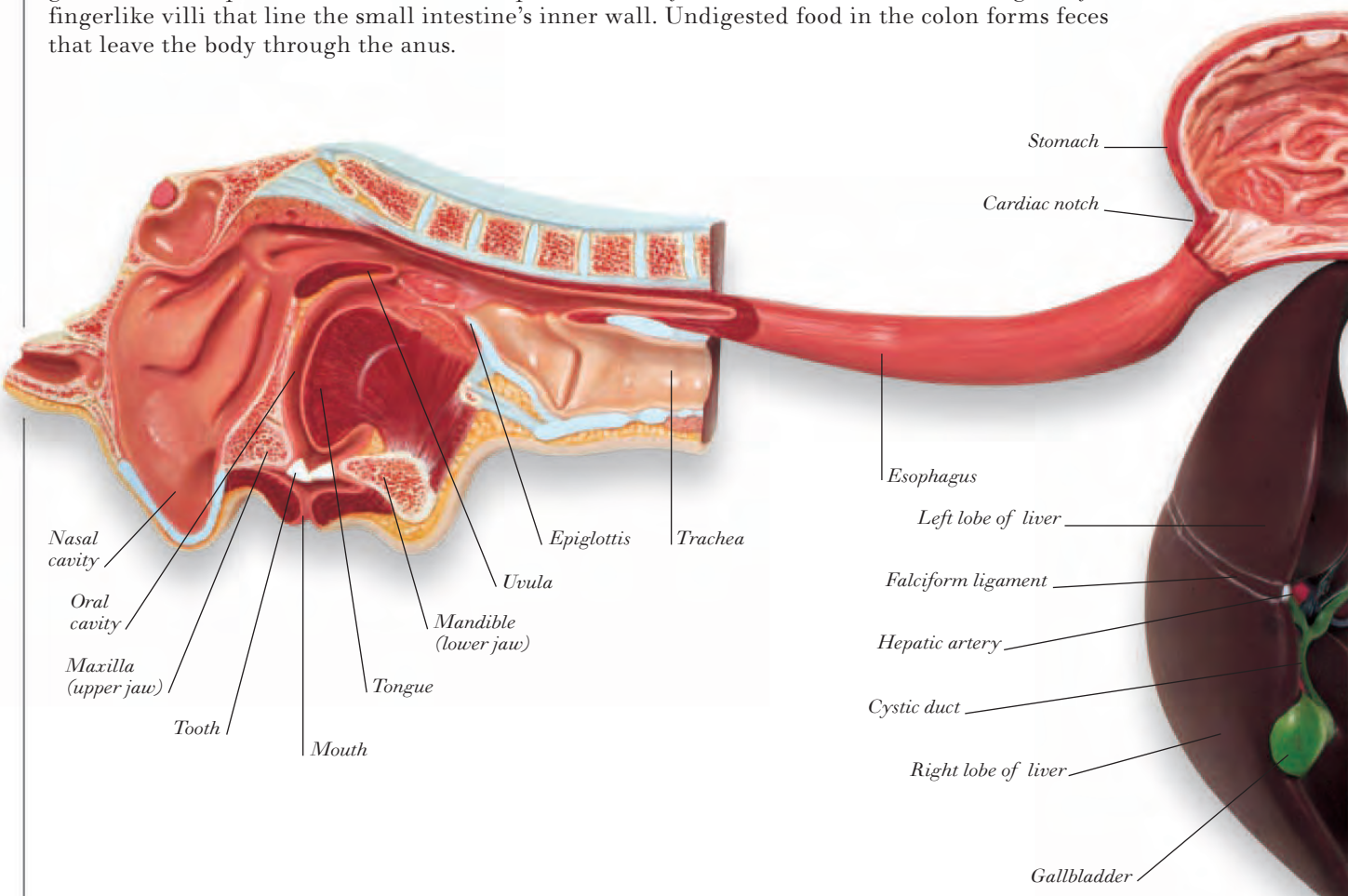


STRUCTURE OF A TOOTH

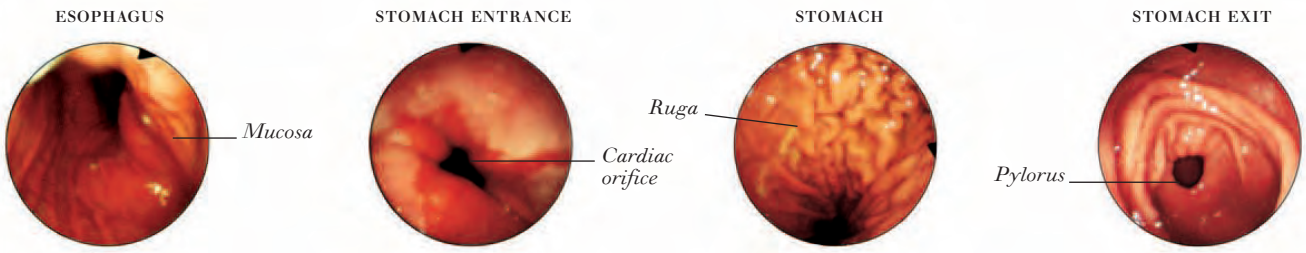


Digestive system

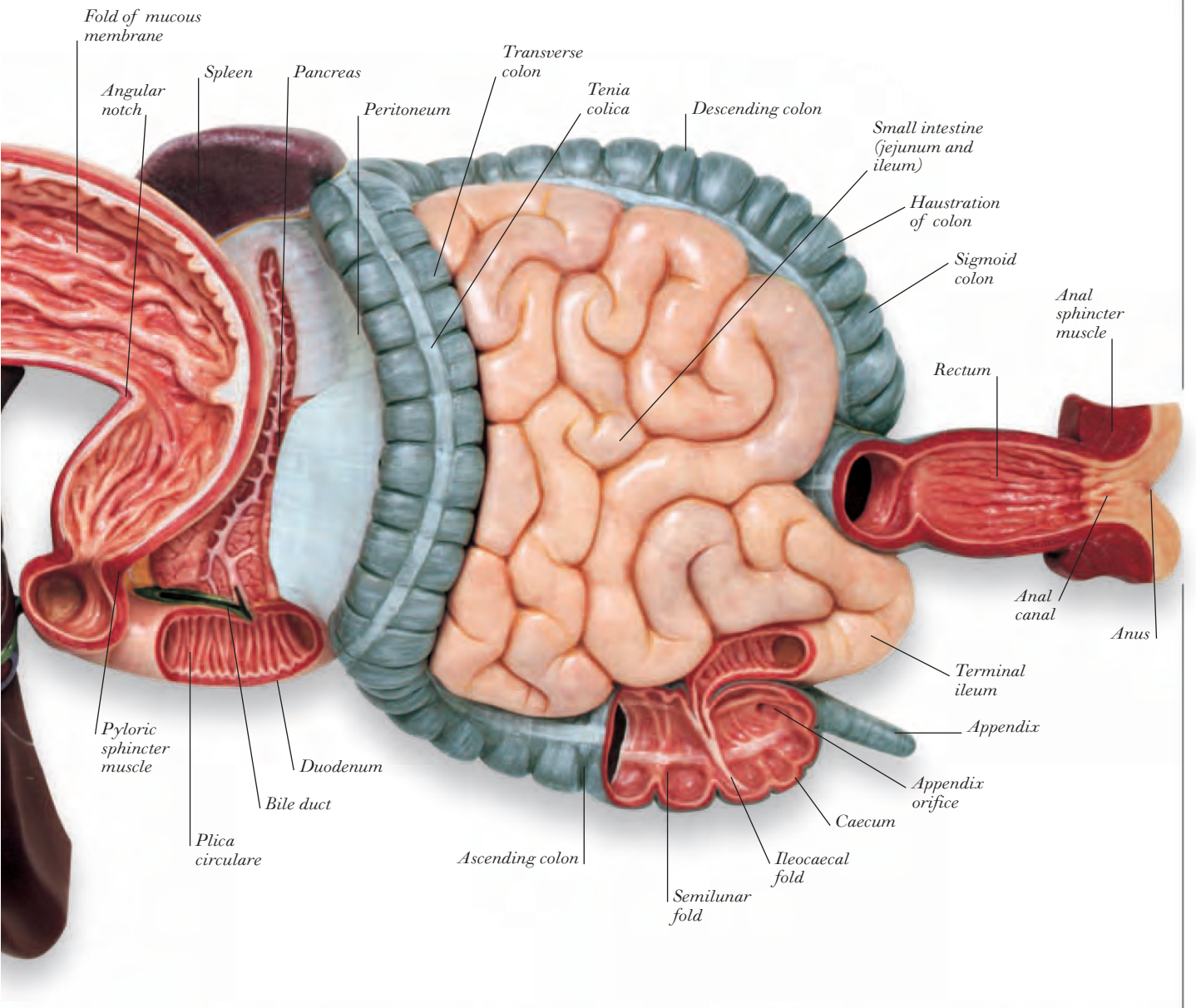
THE DIGESTIVE SYSTEM BREAKS DOWN FOOD into particles so tiny that blood can take nourishment to all parts of the body. The system's main part is a 30 ft (9 m) tube from mouth to rectum; muscles in this alimentary canal force food along. Chewed food first travels through the esophagus to the stomach, which churns and liquidizes food before it passes through the duodenum, jejunum, and ileum—the three parts of the long, convoluted small intestine. Here, digestive juices from the gallbladder and pancreas break down food particles; many filter out into the blood through tiny fingerlike villi that line the small intestine's inner wall. Undigested food in the colon forms feces that leave the body through the anus.

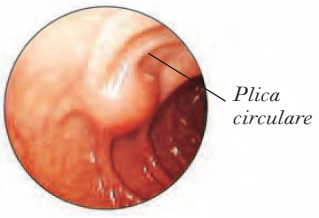


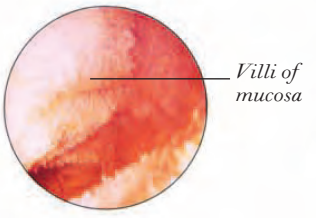
ENDOSCOPIC VIEWS INSIDE ALIMENTARY CANAL

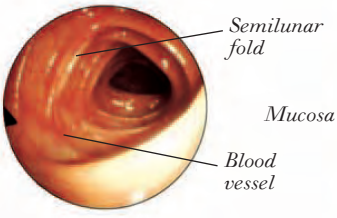


ALIMENTARY CANAL

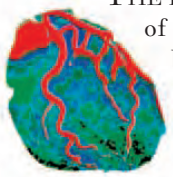






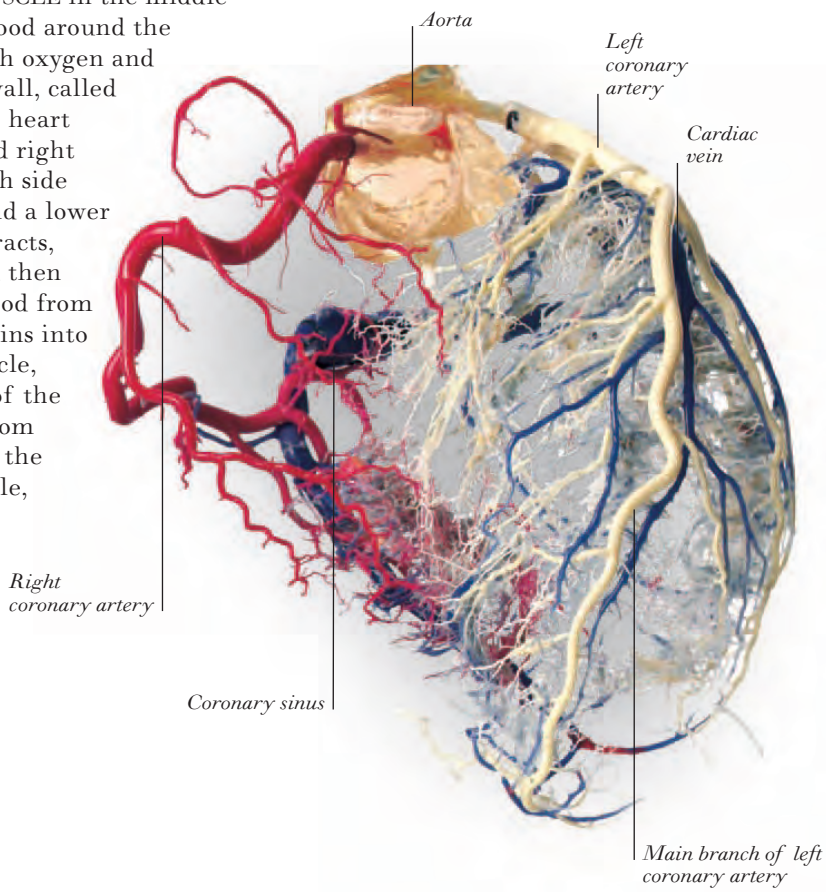


Heart

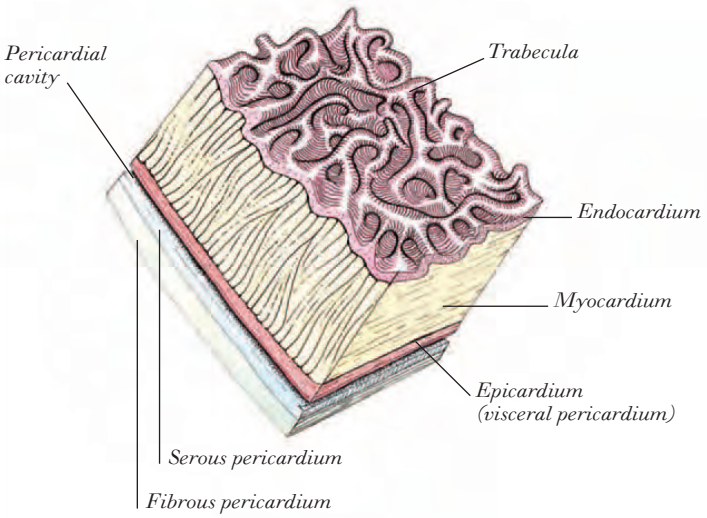


THE HEART IS A HOLLOW MUSCLE in the middle of the chest that pumps blood around the body, supplying cells with oxygen and nutrients. A muscular wall, called the septum, divides the heart lengthwise into left and right sides. A valve divides each side into two chambers: an upper atrium and a lower ventricle. When the heart muscle contracts, it squeezes blood through the atria and then through the ventricles. Oxygenated blood from the lungs flows from the pulmonary veins into the left atrium, through the left ventricle, and then out via the aorta to all parts of the body. Deoxygenated blood returning from the body flows from the vena cava into the right atrium, through the right ventricle, and then out via the pulmonary artery to the lungs for reoxygenation. At rest the heart beats between 60 and 80 times a minute; during exercise or at times of stress or excitement the rate may increase to 200 beats a minute.

ARTERIES AND VEINS SURROUNDING HEART

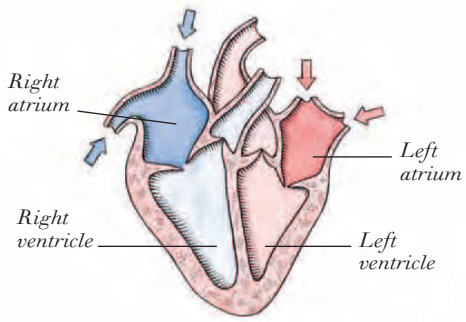


SECTION THROUGH HEART WALL



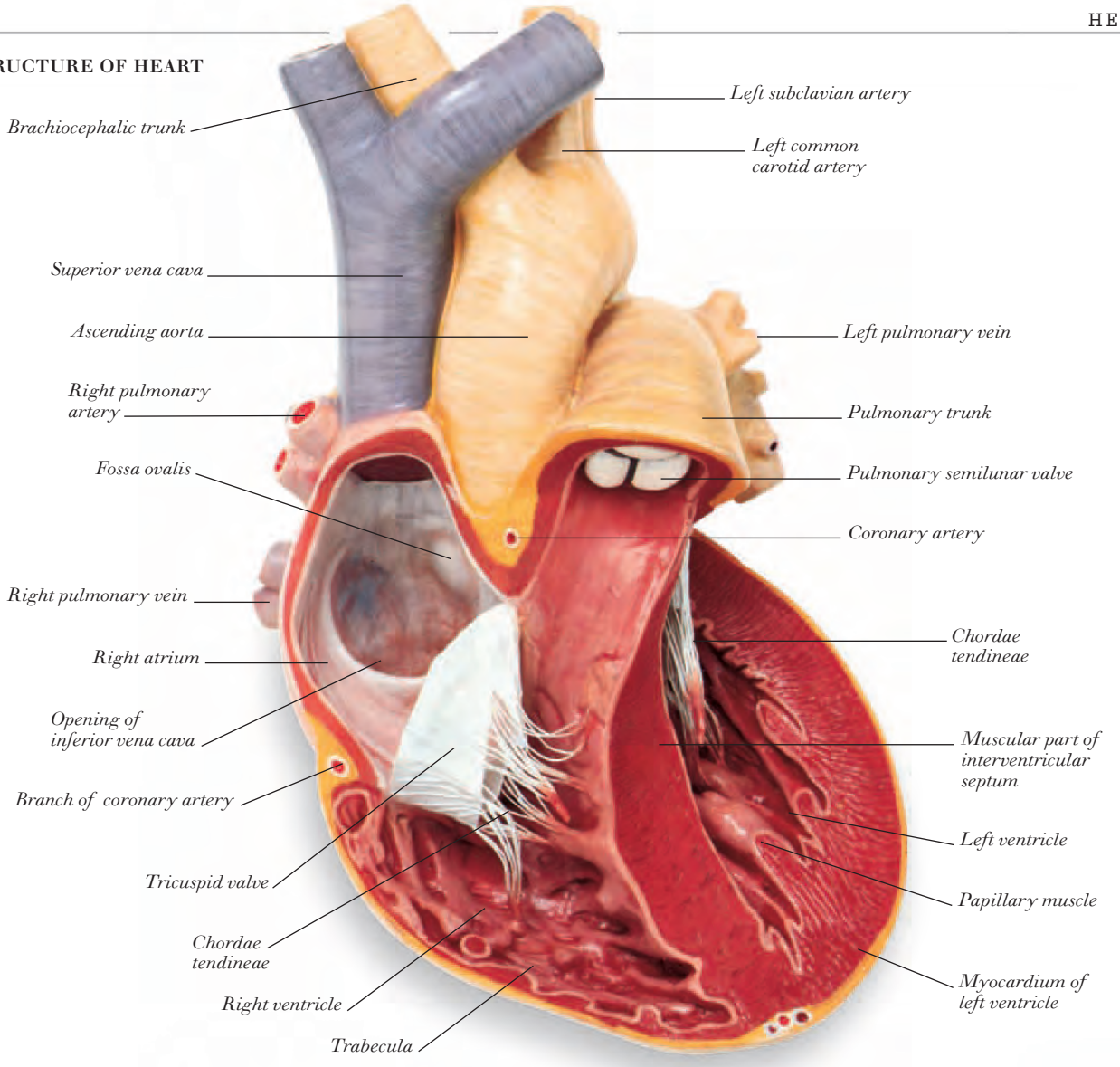
HEARTBEAT SEQUENCE

ATRIAL DIASTOLE

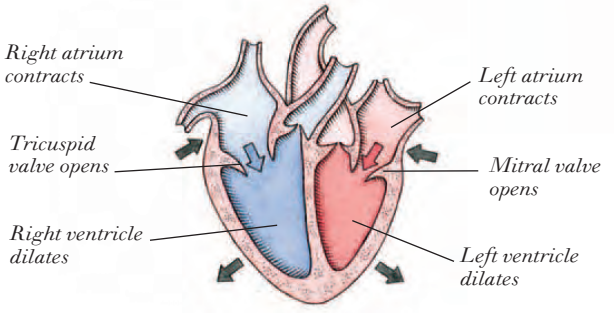


Deoxygenated blood enters the right atrium while the left atrium receives oxygenated blood.

STRUCTURE OF HEART

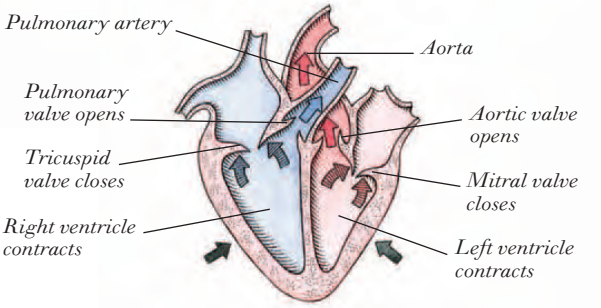


ATRIAL SYSTOLE (VENTRICULAR DIASTOLE)



Left and right atria contract, forcing blood into the relaxed ventricles.

VENTRICULAR SYSTOLE

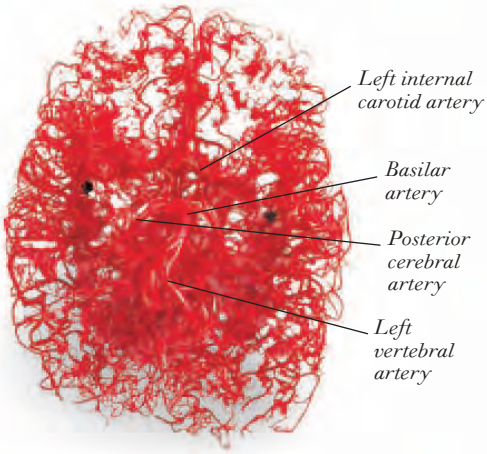


Ventricles contract and force blood to the lungs for oxygenation and via the aorta to the rest of the body.

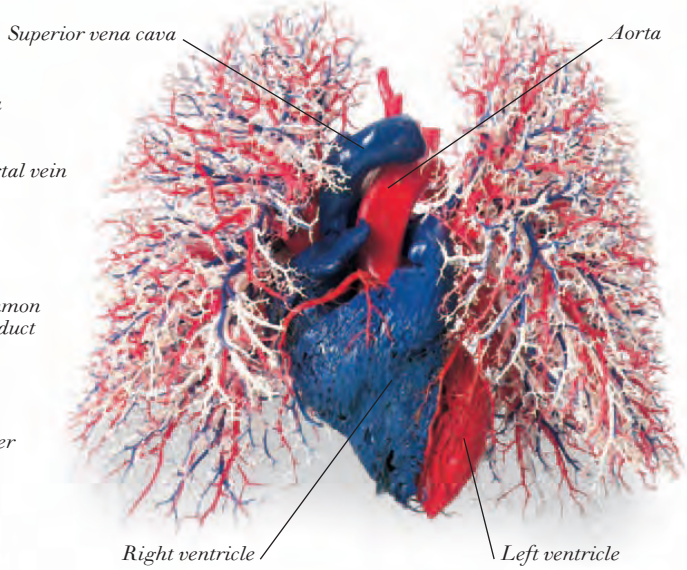
Circulatory system

THE CIRCULATORY SYSTEM consists of the heart and blood vessels, which together maintain a continuous flow of blood around the body. The heart pumps oxygen-rich blood from the lungs to all parts of the body through a network of tubes called arteries, and smaller branches called arterioles. Blood returns to the heart via small vessels called venules, which lead in turn into larger tubes called veins. Arterioles and venules are linked by a network of tiny vessels called capillaries, where the exchange of oxygen and carbon dioxide between blood and body cells takes place. Blood has four main components: red blood cells, white blood cells, platelets, and liquid plasma.

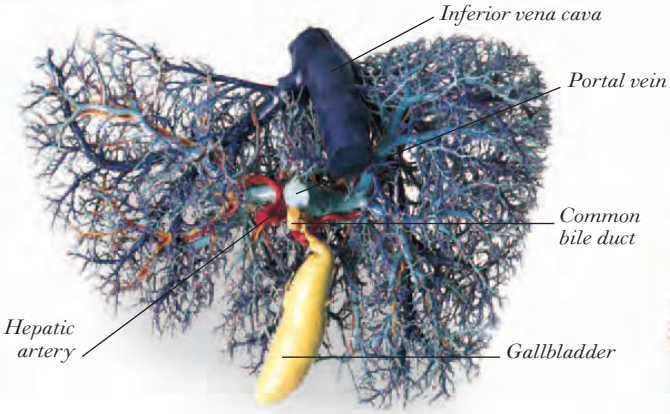
ARTERIAL SYSTEM OF BRAIN



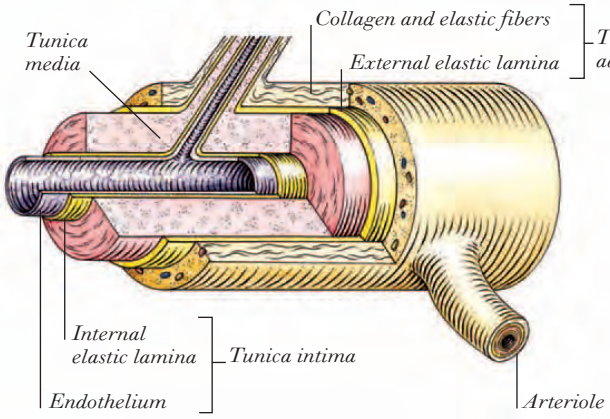
CIRCULATORY SYSTEM OF HEART AND LUNGS



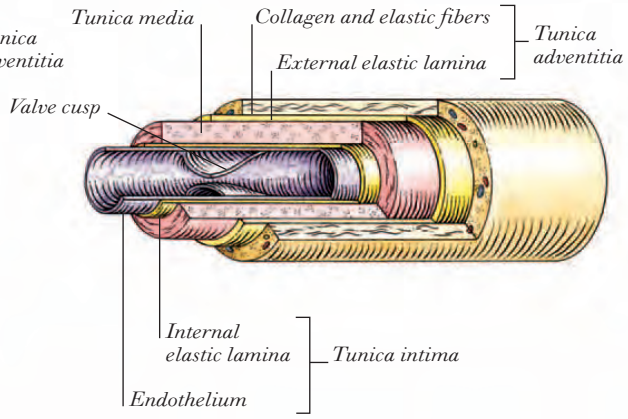
CIRCULATORY SYSTEM OF LIVER



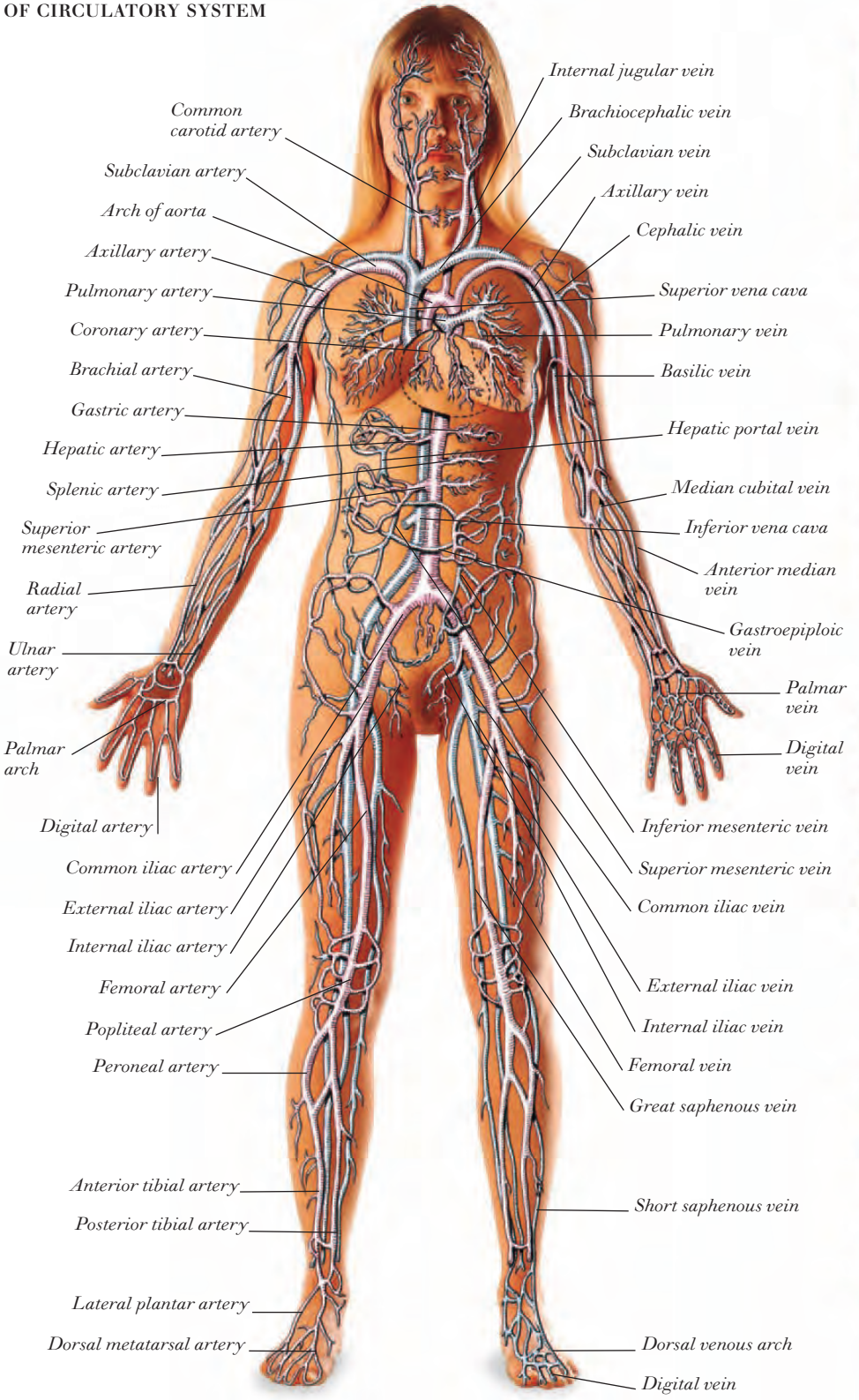
SECTION OF MAIN ARTERY



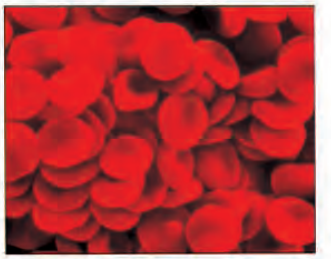
SECTION OF MAIN VEIN



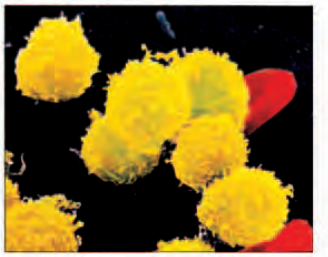
PRINCIPAL ARTERIES AND VEINS OF CIRCULATORY SYSTEM



TYPES OF BLOOD CELLS



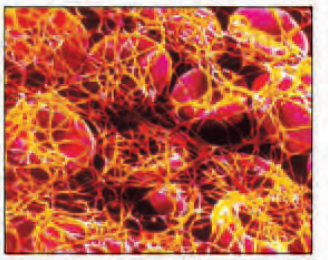
RED BLOOD CELLS
These cells are biconcave in shape to maximize their oxygen-carrying capacity.



WHITE BLOOD CELLS
Lymphocytes are the smallest white blood cells; they form antibodies against disease.

PLATELETS
Tiny cells that are activated whenever blood clotting or repair to vessels is necessary.

BLOOD CLOTTING

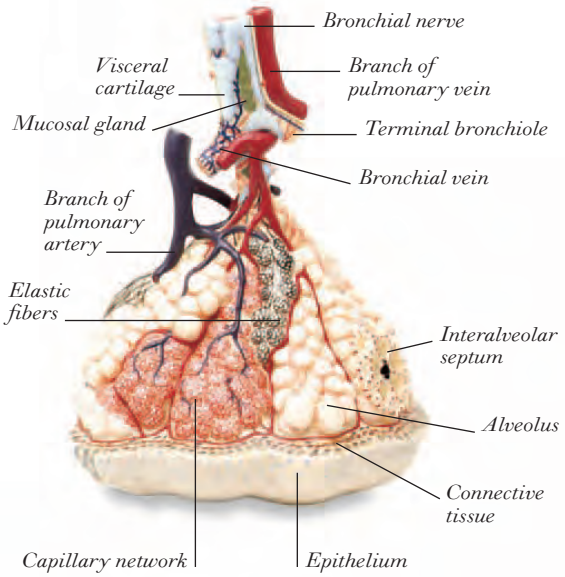


Filaments of fibrin enmesh red blood cells as part of the process of blood clotting.

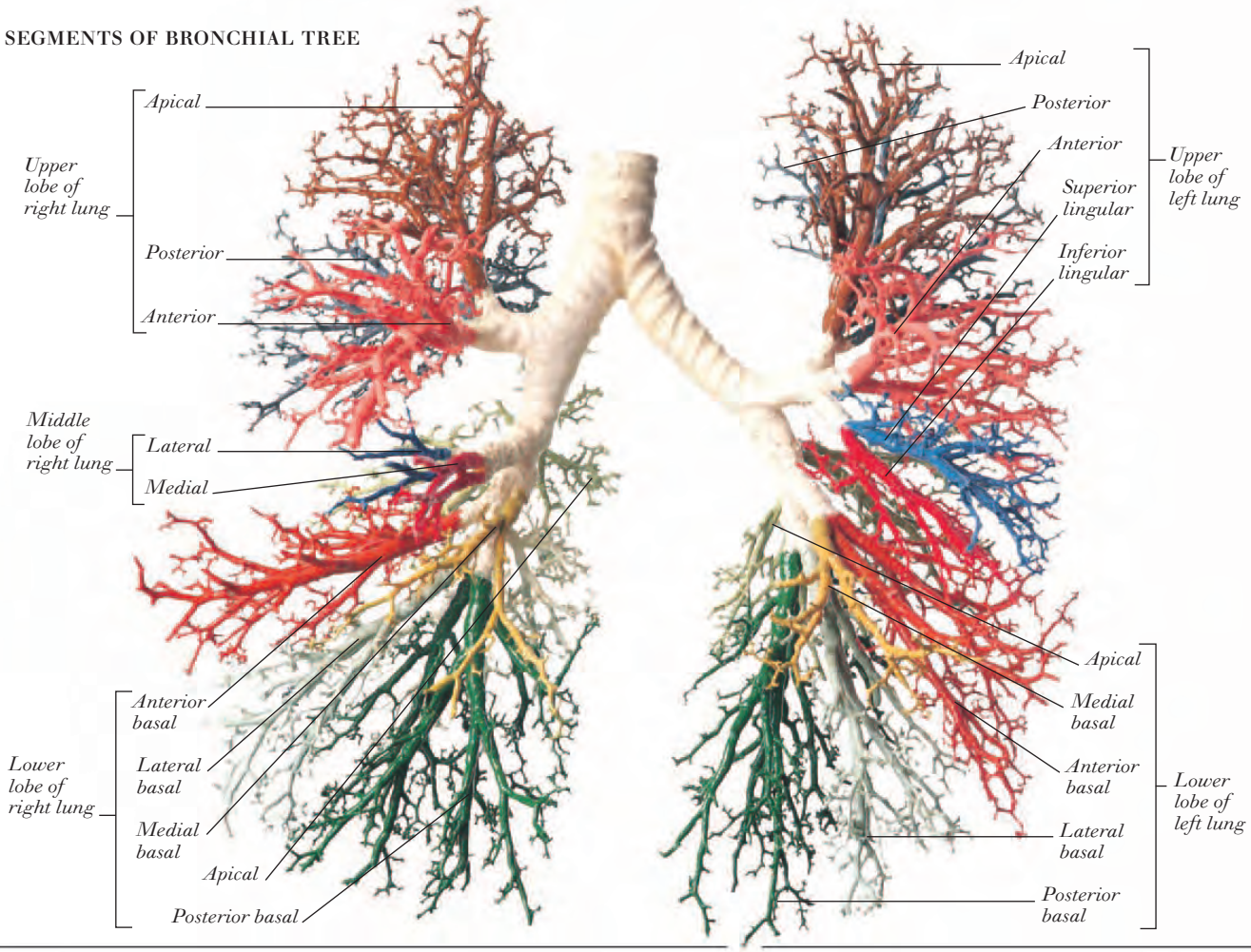
Respiratory system

THE RESPIRATORY SYSTEM supplies the oxygen needed by body cells and carries off their carbon dioxide waste. Inhaled air passes via the trachea (windpipe) through two narrower tubes, the bronchi, to the lungs. Each lung comprises many fine, branching tubes called bronchioles that end in tiny clustered chambers called alveoli. Gases cross the thin alveolar walls to and from a network of tiny blood vessels. Intercostal (rib) muscles and the muscular diaphragm below the lungs operate the lungs like bellows, drawing air in and forcing it out at regular intervals.

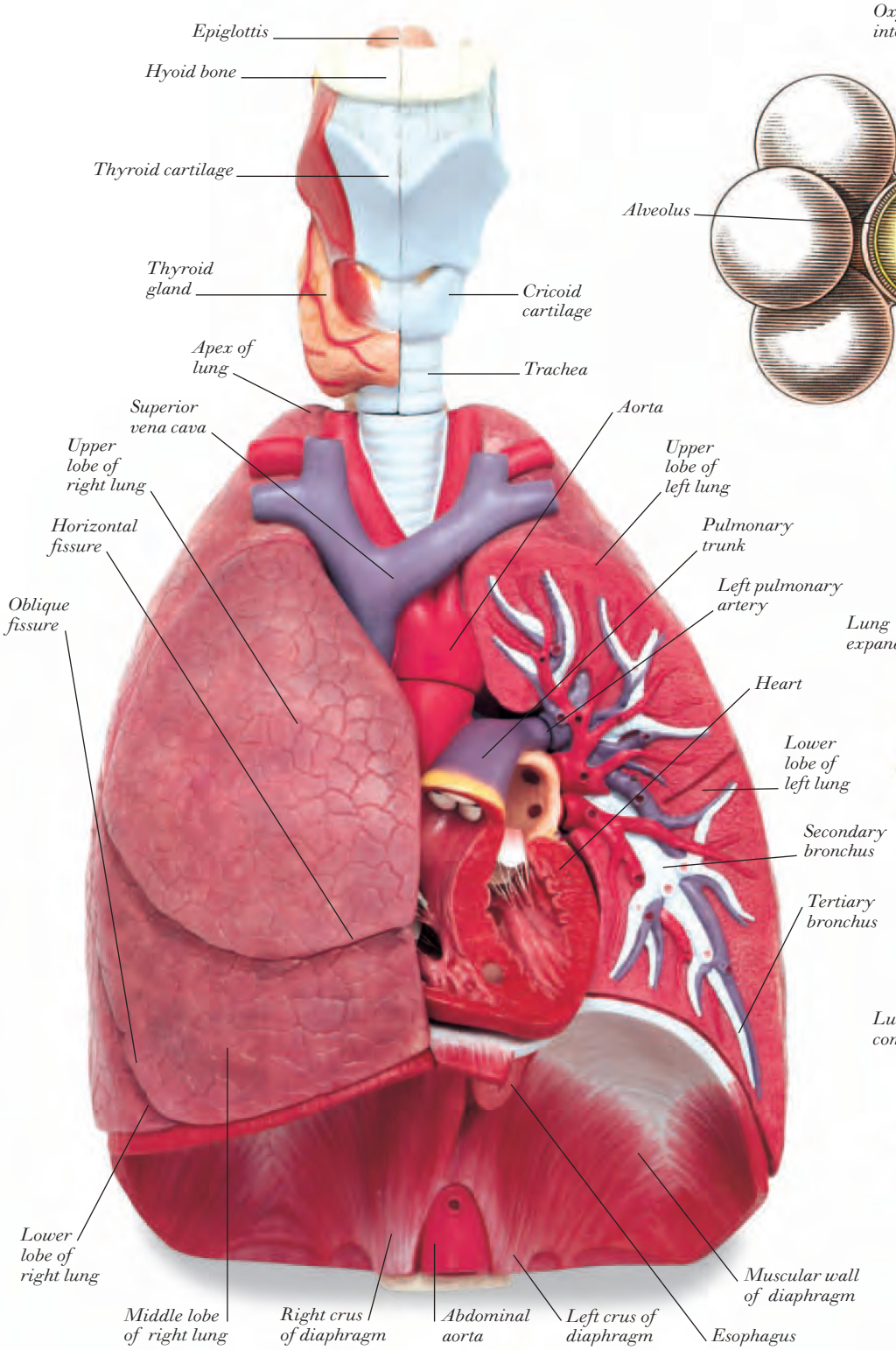
BRONCHIOLE AND ALVEOLI



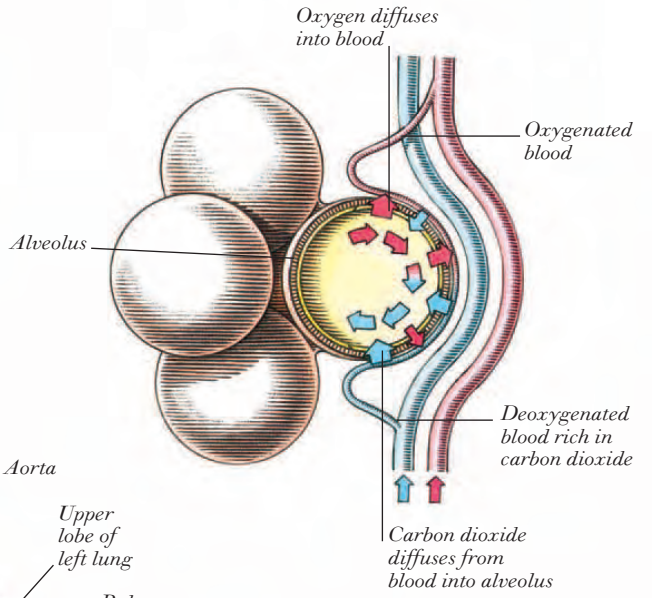
SEGMENTS OF BRONCHIAL TREE



STRUCTURES OF THORACIC CAVITY

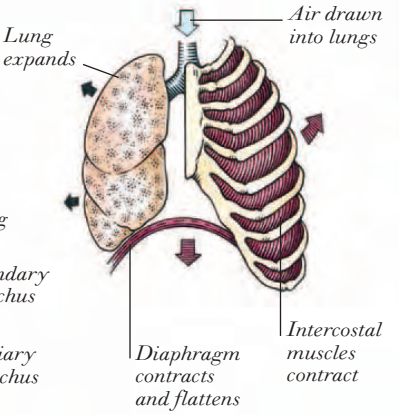


GASEOUS EXCHANGE IN ALVEOLUS

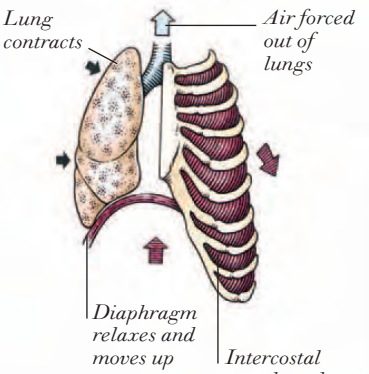


MECHANISM OF RESPIRATION

INSPIRATION



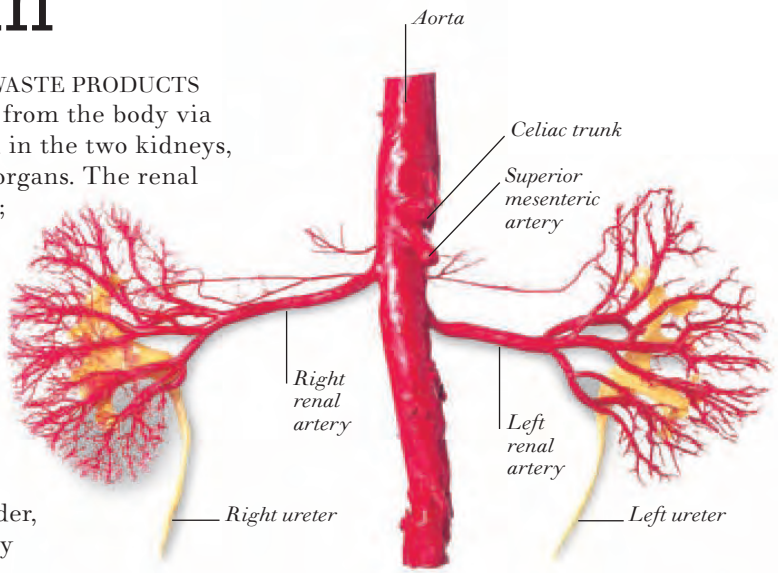
EXPIRATION



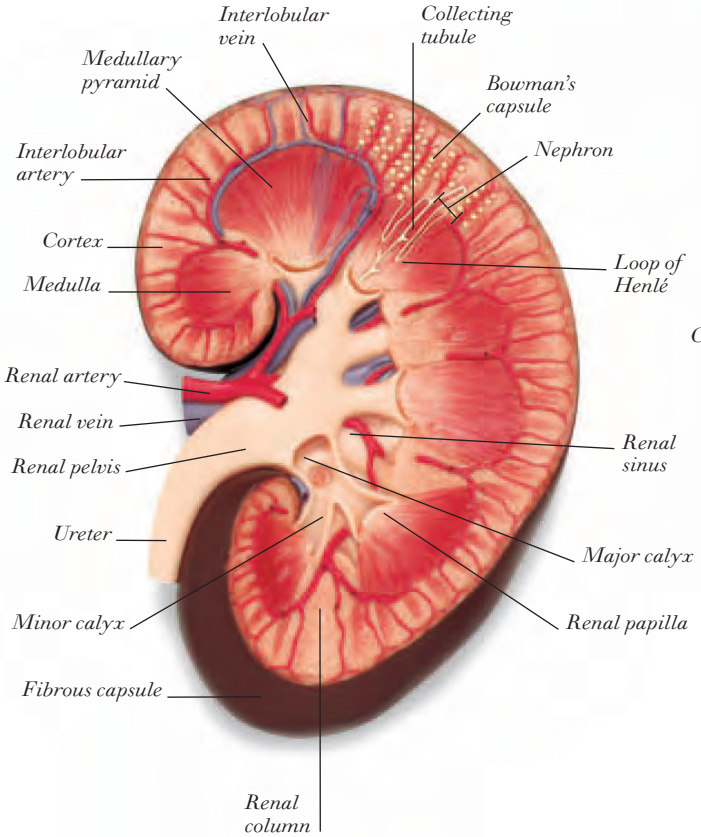
Urinary system

THE URINARY SYSTEM FILTERS WASTE PRODUCTS from the blood and removes them from the body via a system of tubes. Blood is filtered in the two kidneys, which are fist-sized, bean-shaped organs. The renal arteries carry blood to the kidneys; the renal veins remove blood after filtering. Each kidney contains about one million tiny units called nephrons. Each nephron is made up of a tubule and a filtering unit called a glomerulus, which consists of a collection of tiny blood vessels surrounded by the hollow Bowman's capsule. The filtering process produces a watery fluid that leaves the kidney as urine. The urine is carried via two tubes called ureters to the bladder, where it is stored until its release from the body through another tube called the urethra.

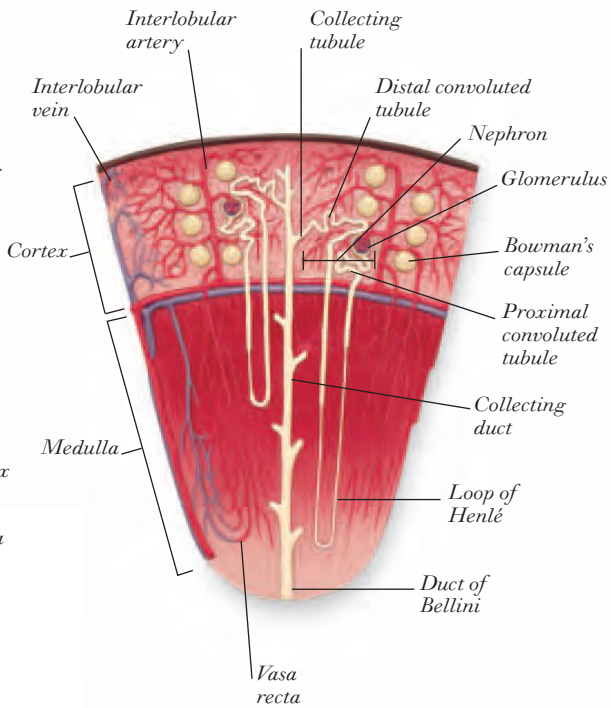
ARTERIAL SYSTEM OF KIDNEYS



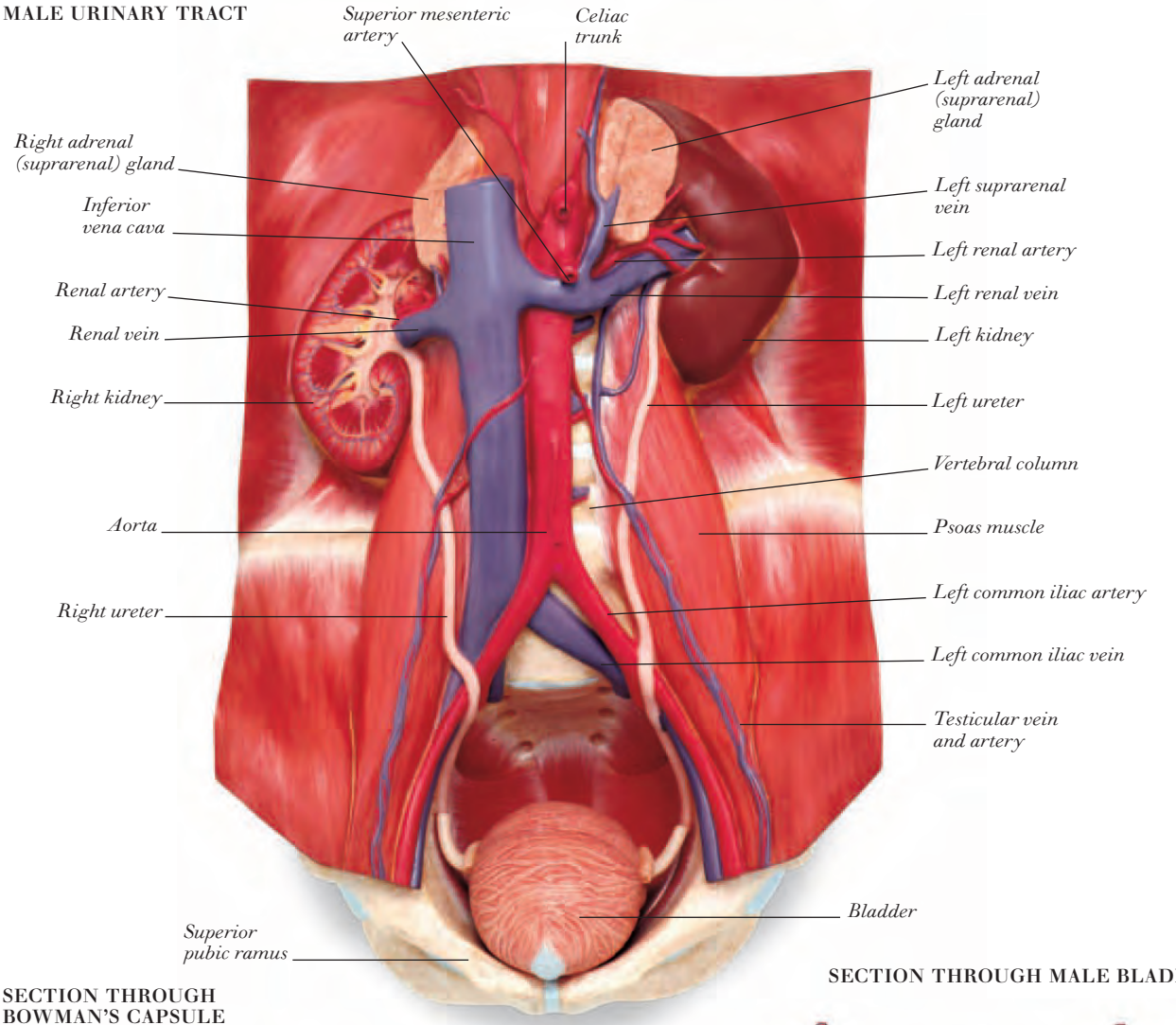
SECTION THROUGH LEFT KIDNEY



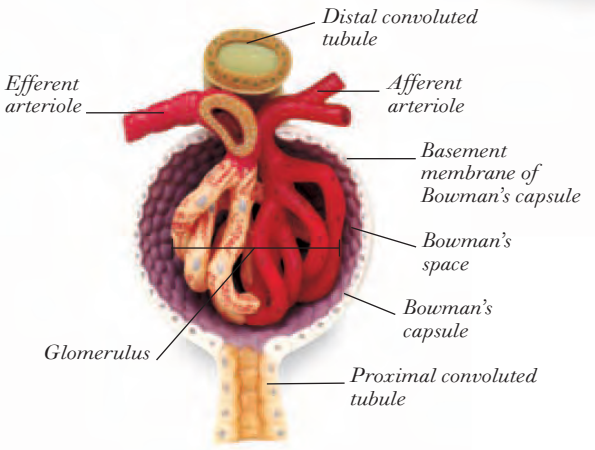
SECTION OF KIDNEY



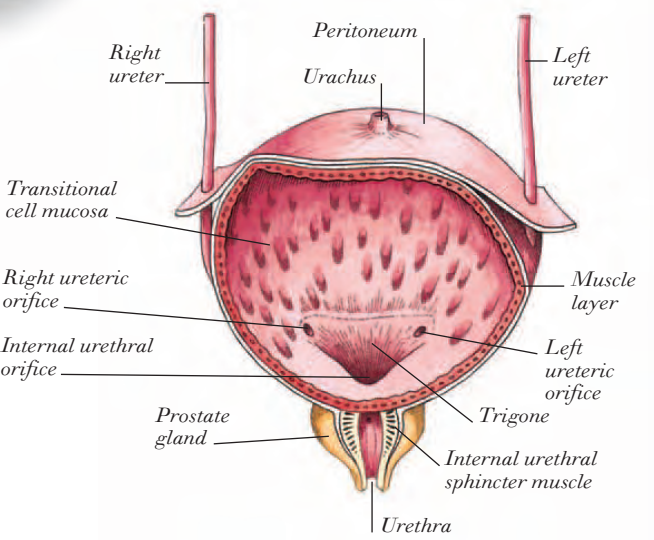
MALE URINARY TRACT



SECTION THROUGH BOWMAN'S CAPSULE



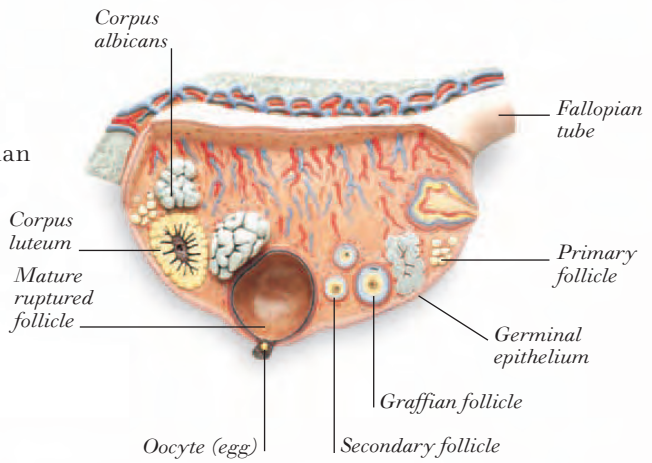
SECTION THROUGH MALE BLADDER



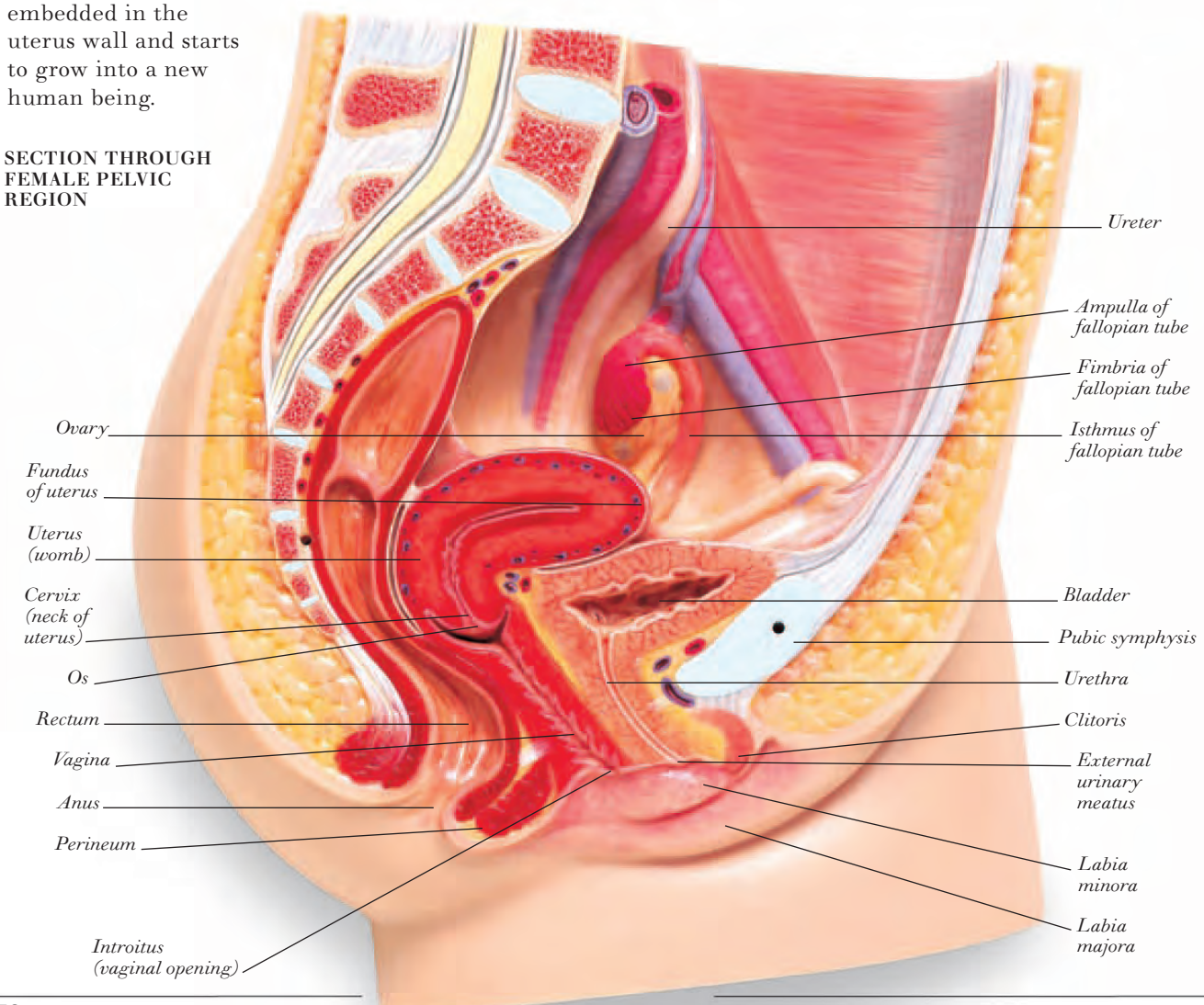
Reproductive system

SEX ORGANS LOCATED IN THE PELVIS create new human lives. Each month a ripe egg is released from one of the female's ovaries into a fallopian tube leading to the uterus (womb), a muscular pear-sized organ. A male produces minute tadpolelike sperm in two oval glands called testes. When the male is ready to release sperm into the female's vagina, many millions pass into his urethra and leave his body through the fleshy penis. The sperm travel up through the vagina into the uterus and fallopian tubes, and one sperm may enter and fertilize an egg. The fertilized egg becomes embedded in the uterus wall and starts to grow into a new human being.

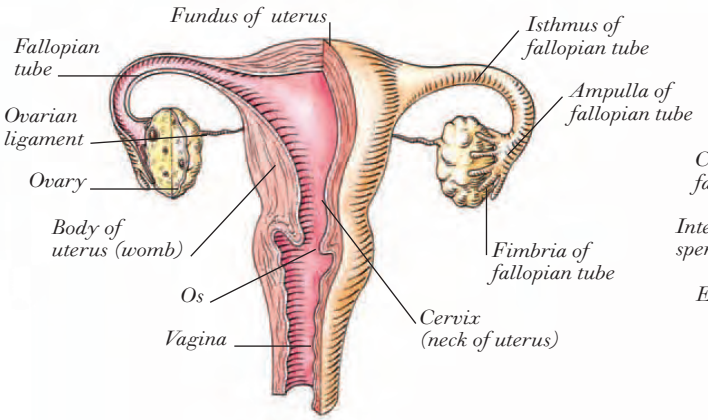
SECTION THROUGH OVARY



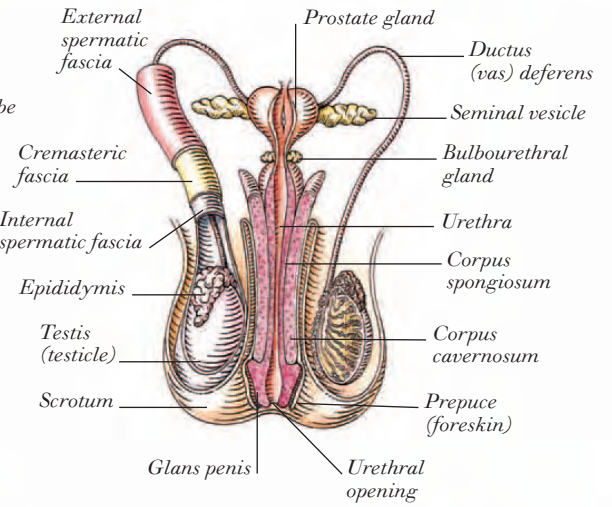
SECTION THROUGH FEMALE PELVIC REGION



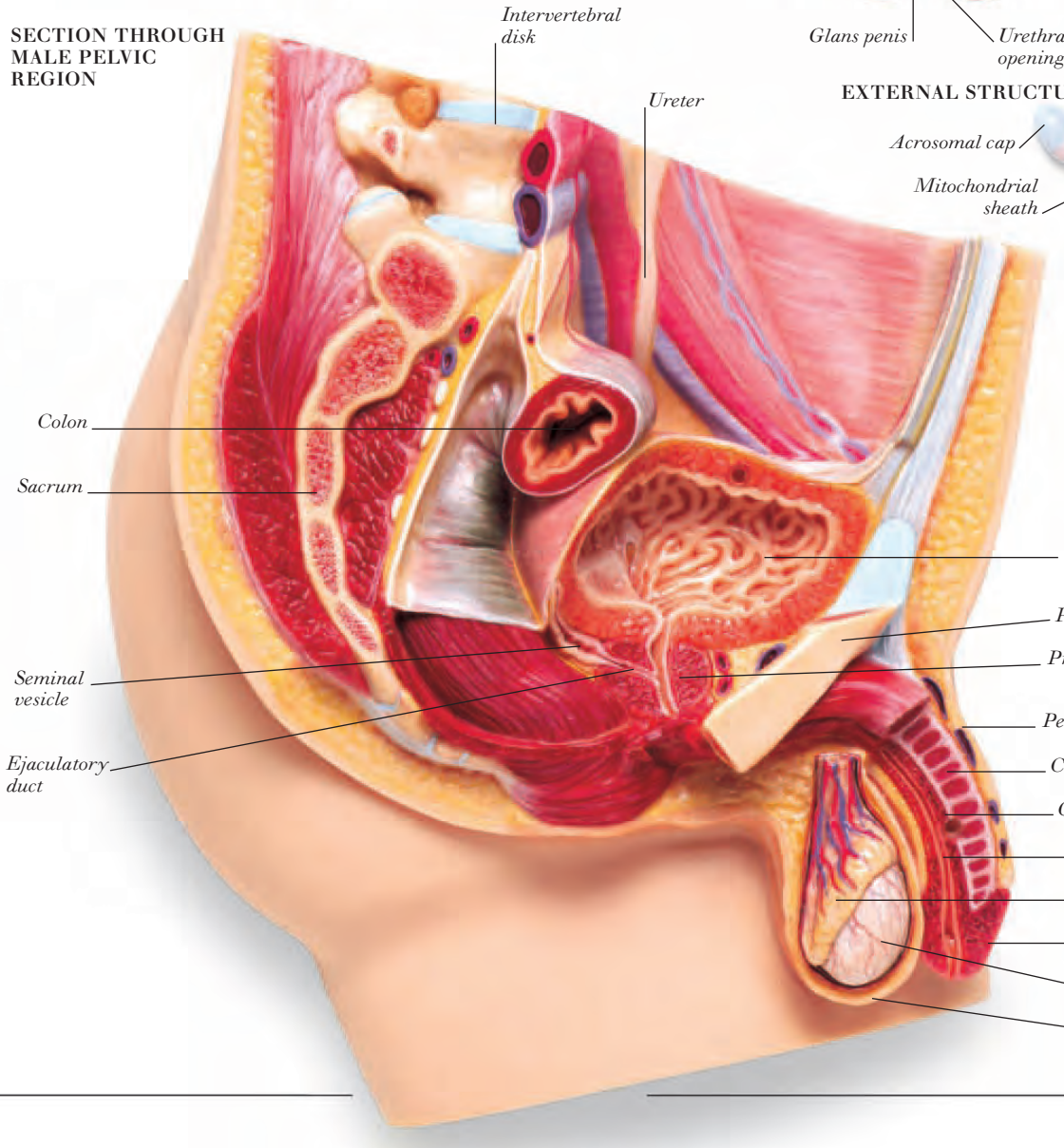
FEMALE REPRODUCTIVE ORGANS



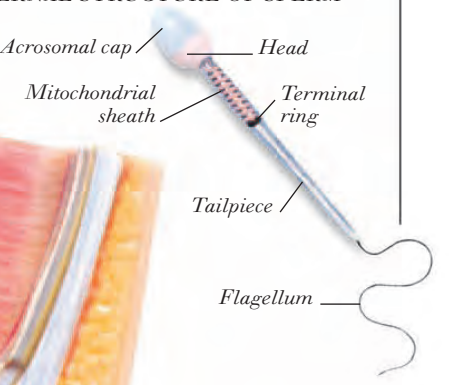
MALE REPRODUCTIVE ORGANS



SECTION THROUGH MALE PELVIC REGION

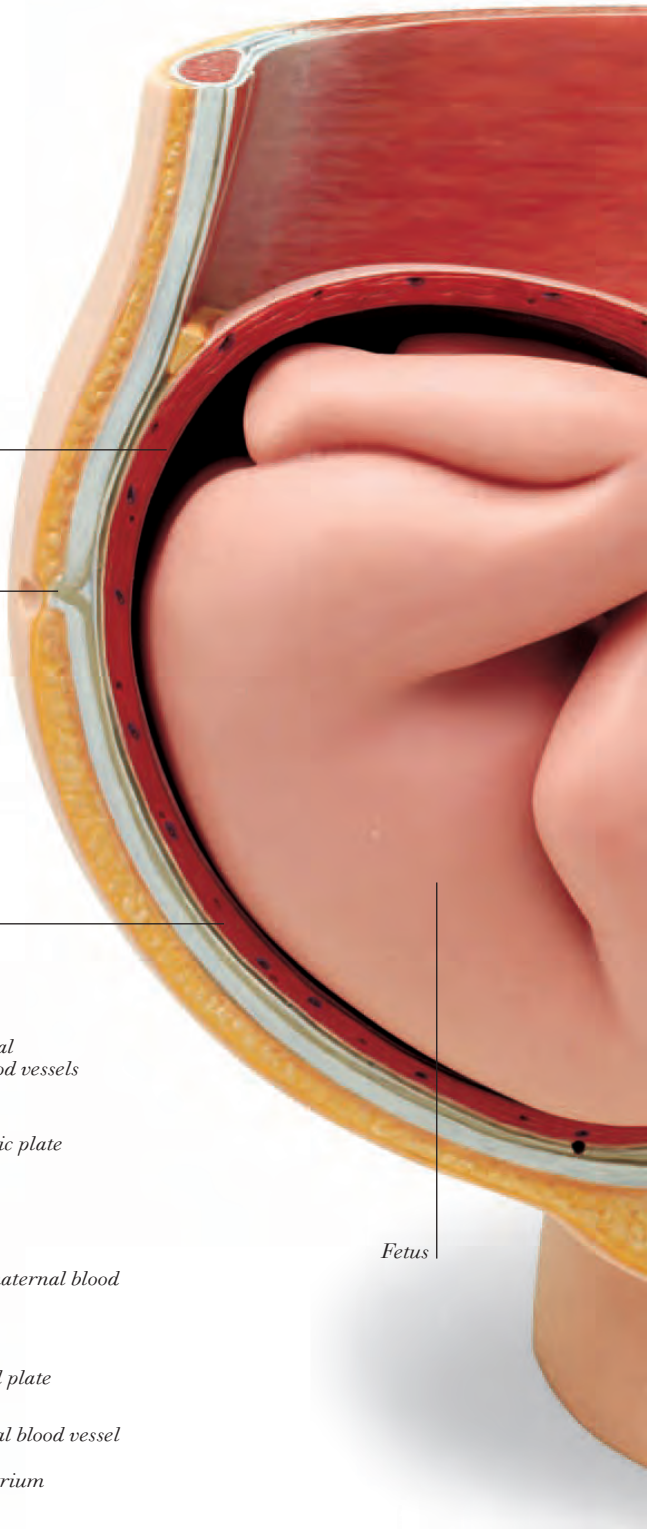


EXTERNAL STRUCTURE OF SPERM

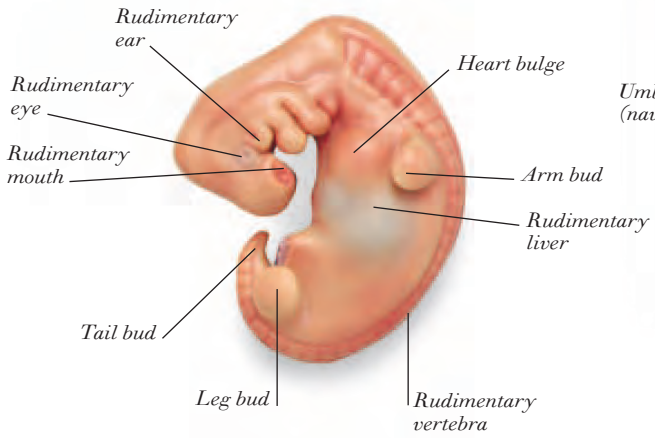


Development of a baby

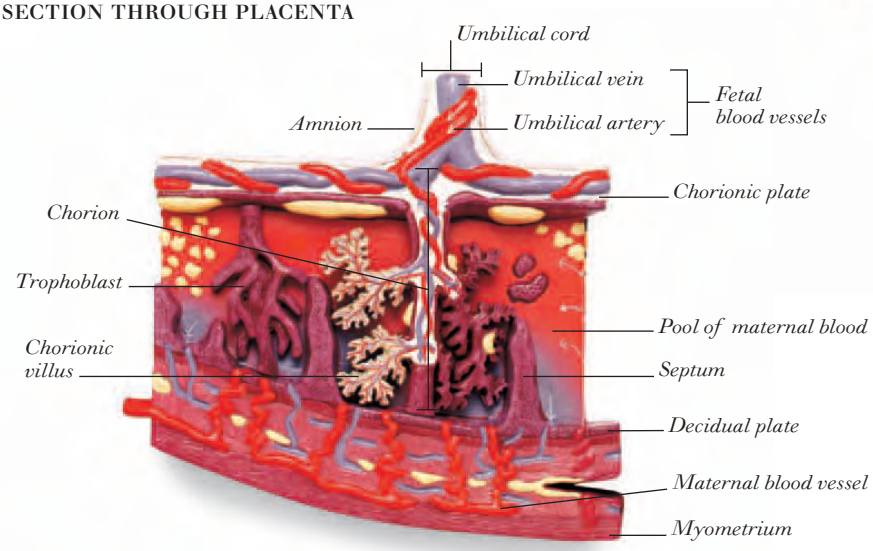
A FERTILIZED EGG IS NOURISHED AND PROTECTED as it develops into an embryo and then a fetus during the 40 weeks of pregnancy. The placenta, a mass of blood vessels implanted in the uterus lining, delivers nourishment and oxygen, and removes waste through the umbilical cord. Meanwhile, the fetus lies snugly in its amniotic sac, a bag of fluid that protects it against any sudden jolts. In the last weeks of the pregnancy, the rapidly growing fetus turns head-down: a baby ready to be born.



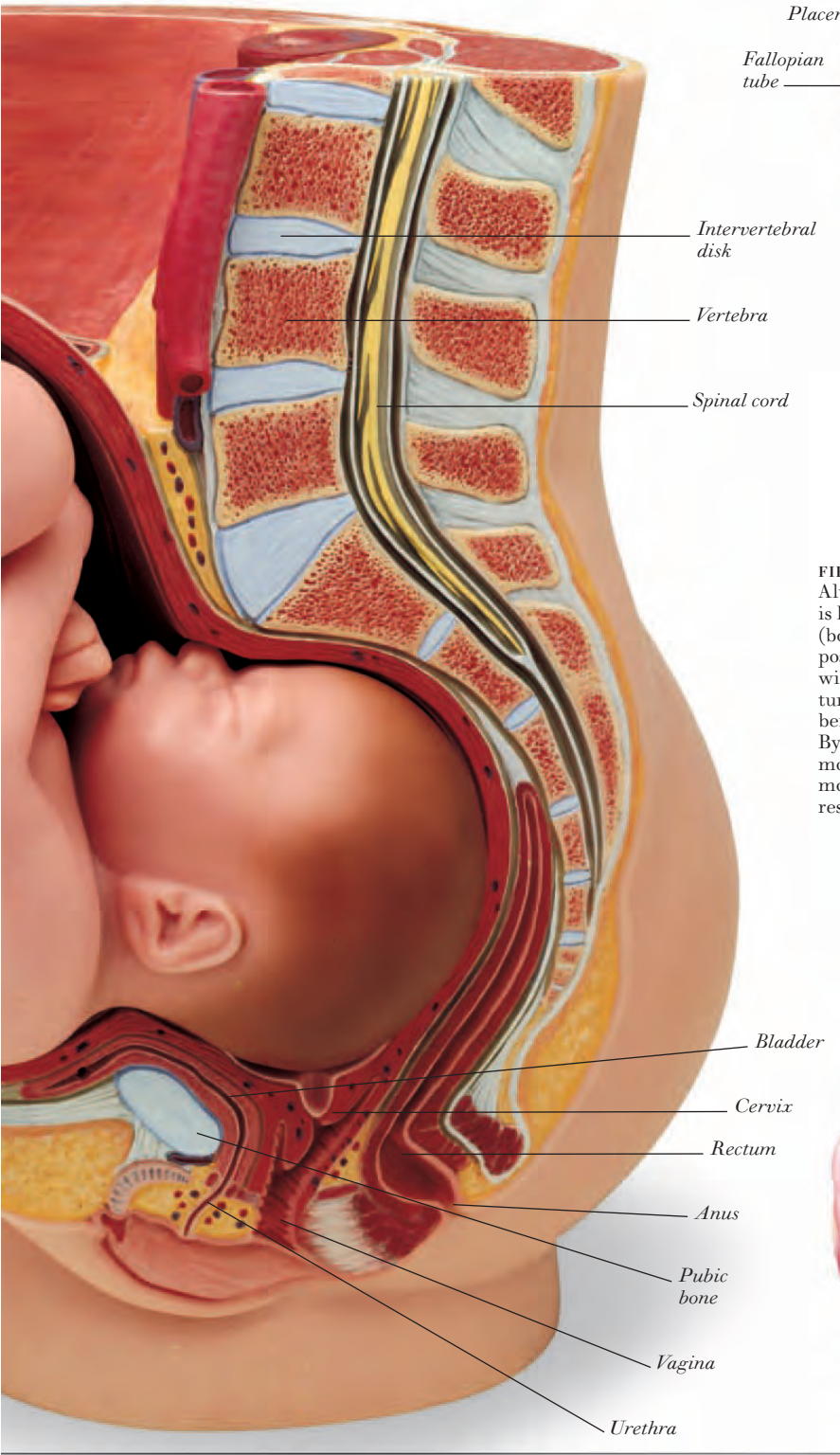
EMBRYO AT FIVE WEEKS



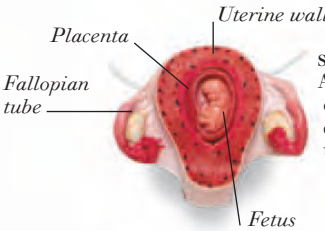
SECTION THROUGH PLACENTA



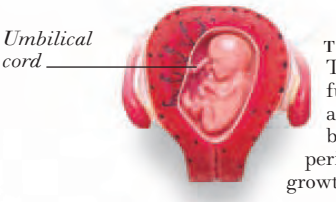
SECTION THROUGH PELVIS IN NINTH MONTH OF PREGNANCY



THE DEVELOPING FETUS

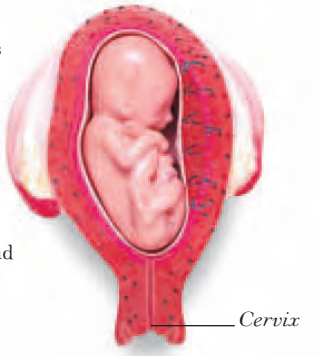


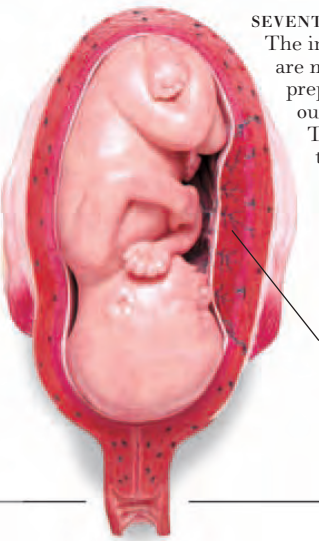
SECOND MONTH
All the internal organs have developed by this stage.



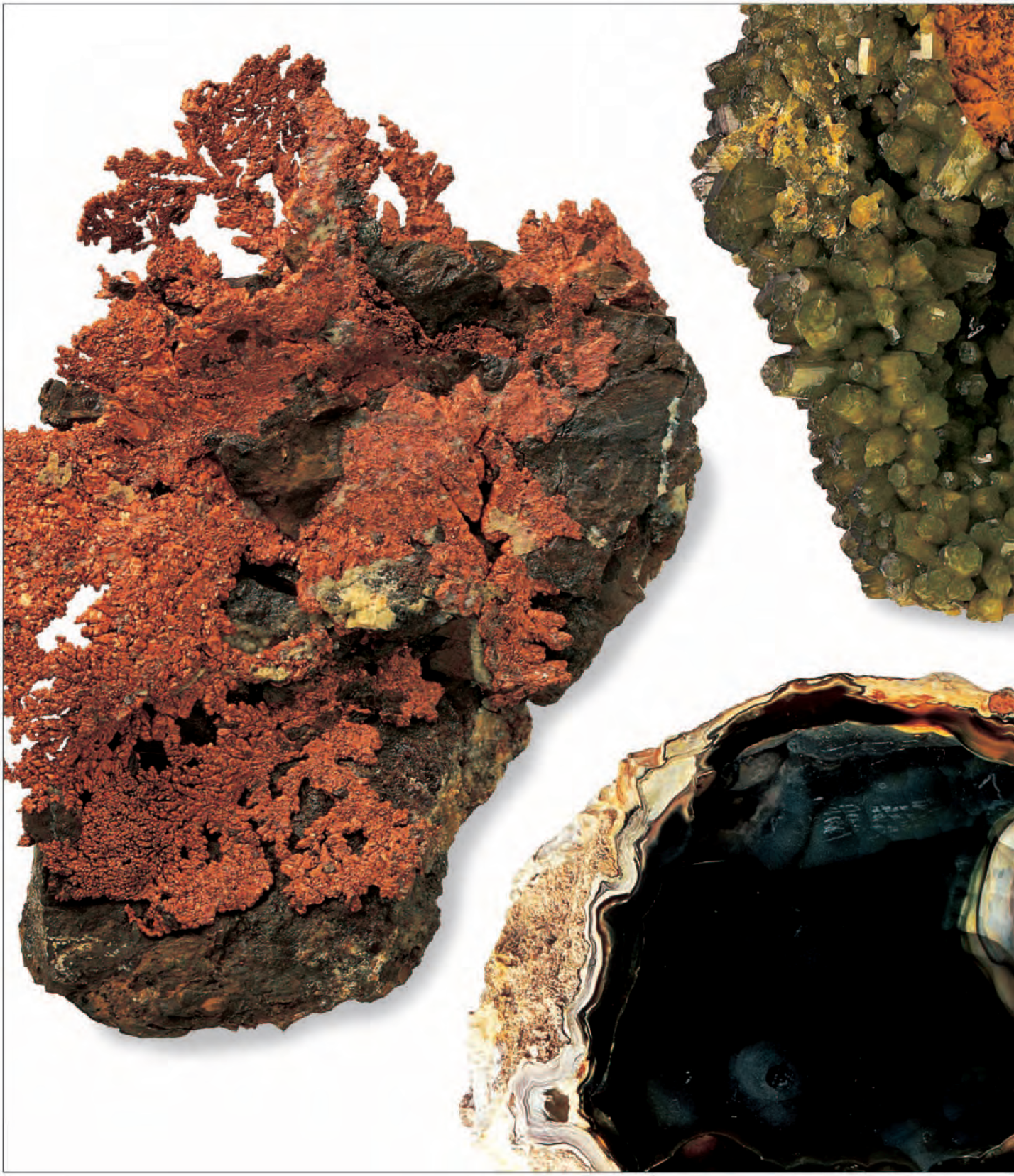
THIRD MONTH
The fetus is fully formed and now begins a period of rapid growth.

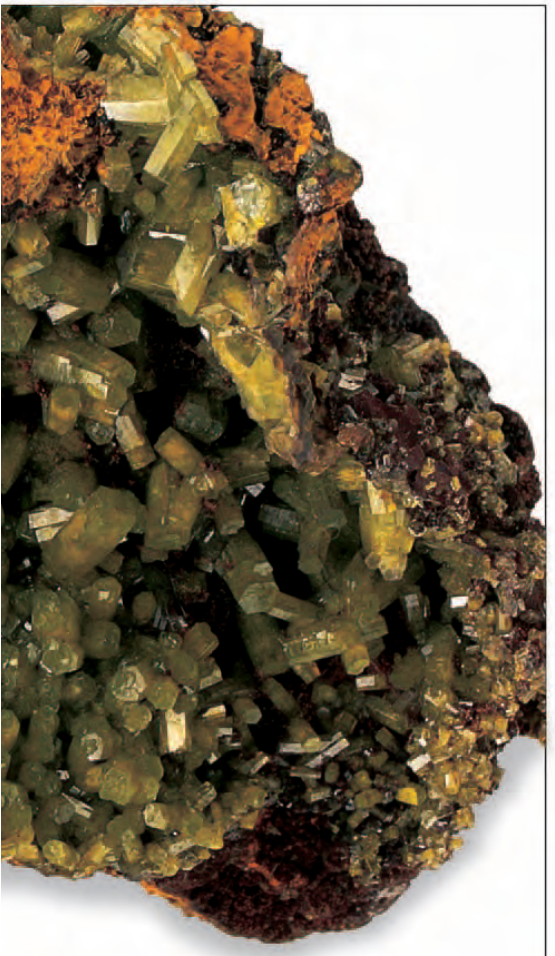
FIFTH MONTH
Although the fetus is here in breech (bottom down) position, it will probably turn by 180° before birth. By the fifth month the baby is moving actively and responds to sound.





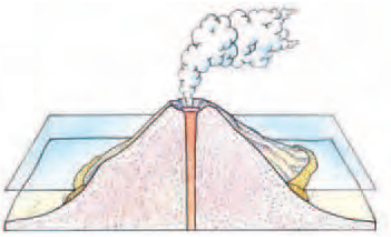
SEVENTH MONTH
The internal organs are maturing in preparation for life outside the uterus. The baby has grown to such a size that there is less room for movement within the uterus.





Geology, Geography, and Meteorology

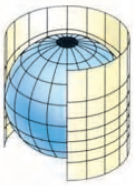
Earth's Physical Features 264
The Rock Cycle 266
Minerals 268
Mineral Features 270
Volcanoes 272
Igneous and Metamorphic Rocks 274
Sedimentary Rocks 276
Fossils 278
Mineral Resources 280
Weathering and Erosion 282
Caves 284
Glaciers 286
Rivers 288
River Features 290
Lakes and Groundwater 292
Coastlines 294
Oceans and Seas 296
The Ocean Floor 298
The Atmosphere 300
Weather 302



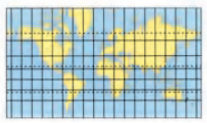
Earth's physical features

MOST OF THE EARTH'S SURFACE (about 70 percent) is covered with water. The largest single body of water, the Pacific Ocean, alone covers about 30 percent of the surface. Most of the land is distributed as seven continents; these are (from largest to smallest) Asia, Africa, North America, South America, Antarctica, Europe, and Australasia. The physical features of the land are remarkably varied. Among the most notable are mountain ranges, rivers, and deserts. The largest mountain ranges—the Himalayas in Asia and the Andes in South America—extend for thousands of miles. The Himalayas include the world's highest mountain, Mount Everest (29,029 ft/8,848 m). The longest rivers are the Nile River in Africa (4,160 miles/6,695 km) and the Amazon River in South America (4,000 miles/6,437 km). Deserts cover about 20 percent of the total land area. The largest is the Sahara, which covers nearly a third of Africa. The Earth's surface features can be represented in various ways. Only a globe can correctly represent areas, shapes, sizes, and directions, because there is always distortion when a spherical surface—the Earth's, for example—is projected on to the flat surface of a map. Each map projection is therefore a compromise; it shows some features accurately but distorts others. Even satellite mapping does not produce completely accurate maps, although they can show physical features with great clarity.

EXAMPLES OF MAP PROJECTIONS

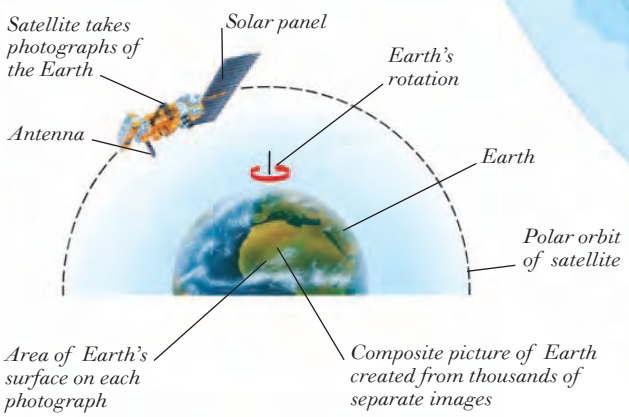


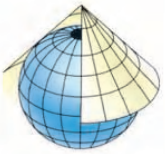
CYLINDRICAL PROJECTION



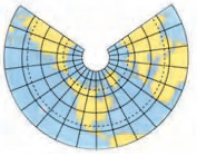
CYLINDRICAL-PROJECTION MAP

SATELLITE MAPPING OF THE EARTH

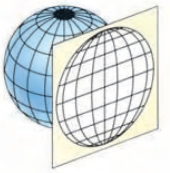




CONICAL PROJECTION

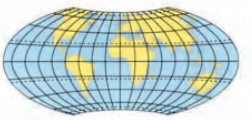


CONICAL-PROJECTION MAP



AZIMUTHAL PROJECTION

AZIMUTHAL-PROJECTION MAP



MODIFIED AZIMUTHAL-PROJECTION MAP

SATELLITE MAP OF THE EARTH

160° 180° 120° 80° 40° 0° 40°

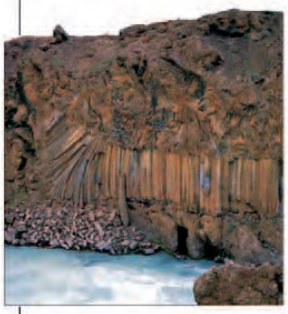
ARCTIC OCEAN
Sea of Azov
Caucasus
Ural Mountains
Kara Kum
River Ob-Irtysh
River Lena
Carpathians
Alps
ARCTIC CIRCLE (66° 32'N)
River Amur
Pyrenees
EUROPE
Black Sea
ASIA
Lake Baikal
Sea of Japan
Atlas Mountains
Mediterranean Sea
Honshu
Sahara
Gobi Desert
TROPIC OF CANCER (23° 30 N)
Yellow River (Huang He)
PACIFIC OCEAN
Red Sea
AFRICA
Pamirs
South China Sea
Yangtze River (Chang Jiang)
Caspian Sea
Himalayas
Thar Desert
River Mekong
Arabian Desert
Takla Makan Desert
Borneo
New Guinea
EQUATOR (0°)
River Nile
River Congo (Zaire)
Lake Victoria
Sumatra
Lake Tanganyika
INDIAN OCEAN
Australian Desert
AUSTRALASIA
Madagascar
Namib Desert
TROPIC OF CAPRICORN (23° 30'S)
Lake Nyasa
Kalahari Desert
Drakensberg
New Zealand
ANTARCTIC CIRCLE (66° 32'S)
ANTARCTICA

40° 0° 40° 80° 120° 160° 180°

GREENWICH MERIDIAN

EAST OF GREENWICH MERIDIAN

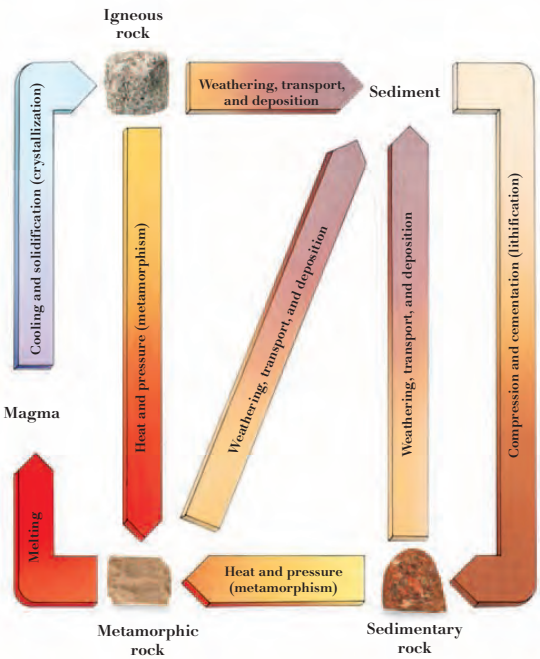
The rock cycle



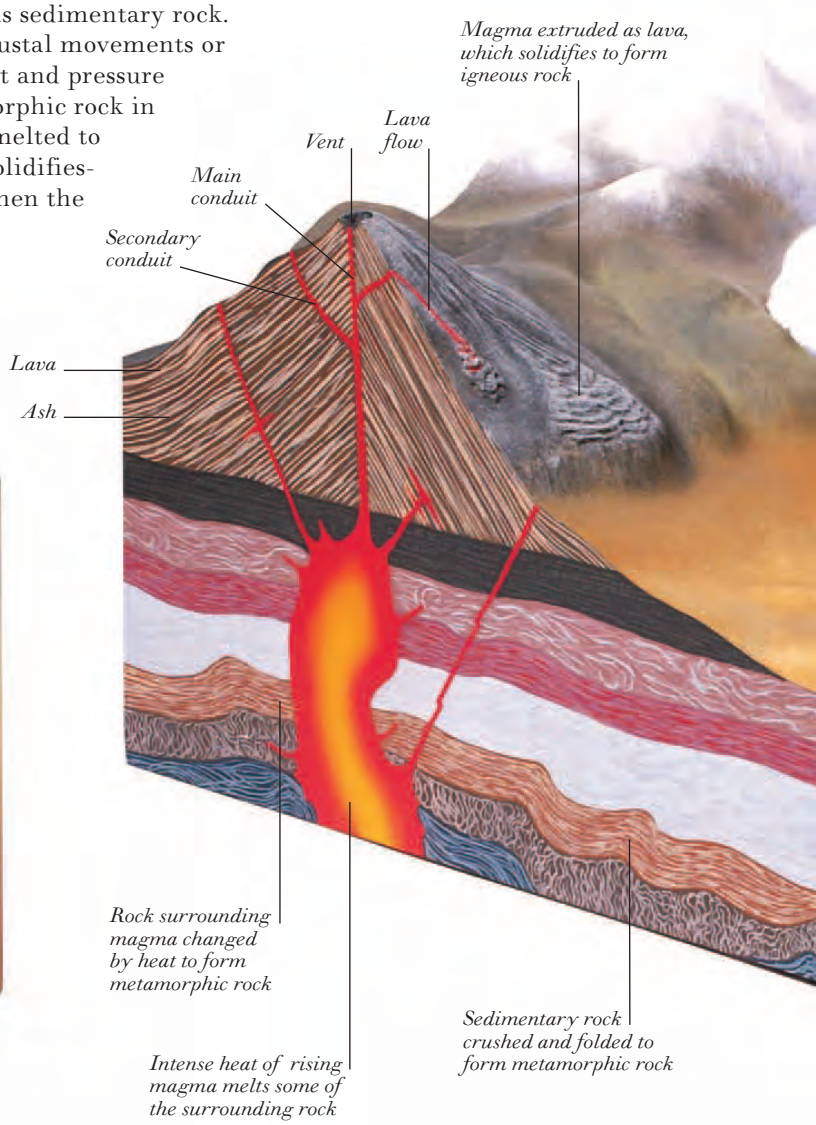
HEXAGONAL BASALT COLUMNS, ICELAND

THE ROCK CYCLE IS A CONTINUOUS PROCESS through which old rocks are transformed into new ones. Rocks can be divided into three main groups: igneous, sedimentary, and metamorphic. Igneous rocks are formed when magma (molten rock) from the Earth's interior cools and solidifies (see pp. 274-275). Sedimentary rocks are formed when sediment (rock particles, for example) becomes compressed and cemented together in a process known as lithification (see pp. 276-277). Metamorphic rocks are formed when igneous, sedimentary, or other metamorphic rocks are changed by heat or pressure (see pp. 274-275). Rocks are added to the Earth's surface by crustal movements and volcanic activity. Once exposed on the surface, the rocks are broken down into rock particles by weathering (see pp. 282-283). The particles are then transported by glaciers, rivers, and wind, and deposited as sediment in lakes, deltas, deserts, and on the ocean floor. Some of this sediment undergoes lithification and forms sedimentary rock. This rock may be thrust back to the surface by crustal movements or forced deeper into the Earth's interior, where heat and pressure transform it into metamorphic rock. The metamorphic rock in turn may be pushed up to the surface or may be melted to form magma. Eventually, the magma cools and solidifies-below or on the surface-forming igneous rock. When the sedimentary, igneous, and metamorphic rocks are exposed once more on the Earth's surface, the cycle begins again.

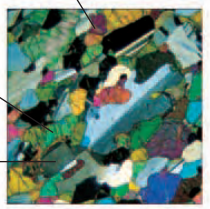
THE ROCK CYCLE



STAGES IN THE ROCK CYCLE



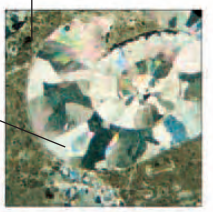
IGNEOUS ROCK



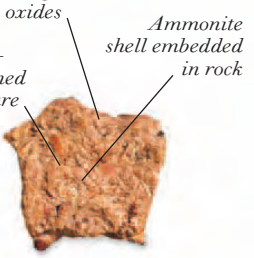
PHOTOMICROGRAPH OF GABBRO

PIECE OF GABBRO

SEDIMENTARY ROCK



PHOTOMICROGRAPH OF SHELLY LIMESTONE

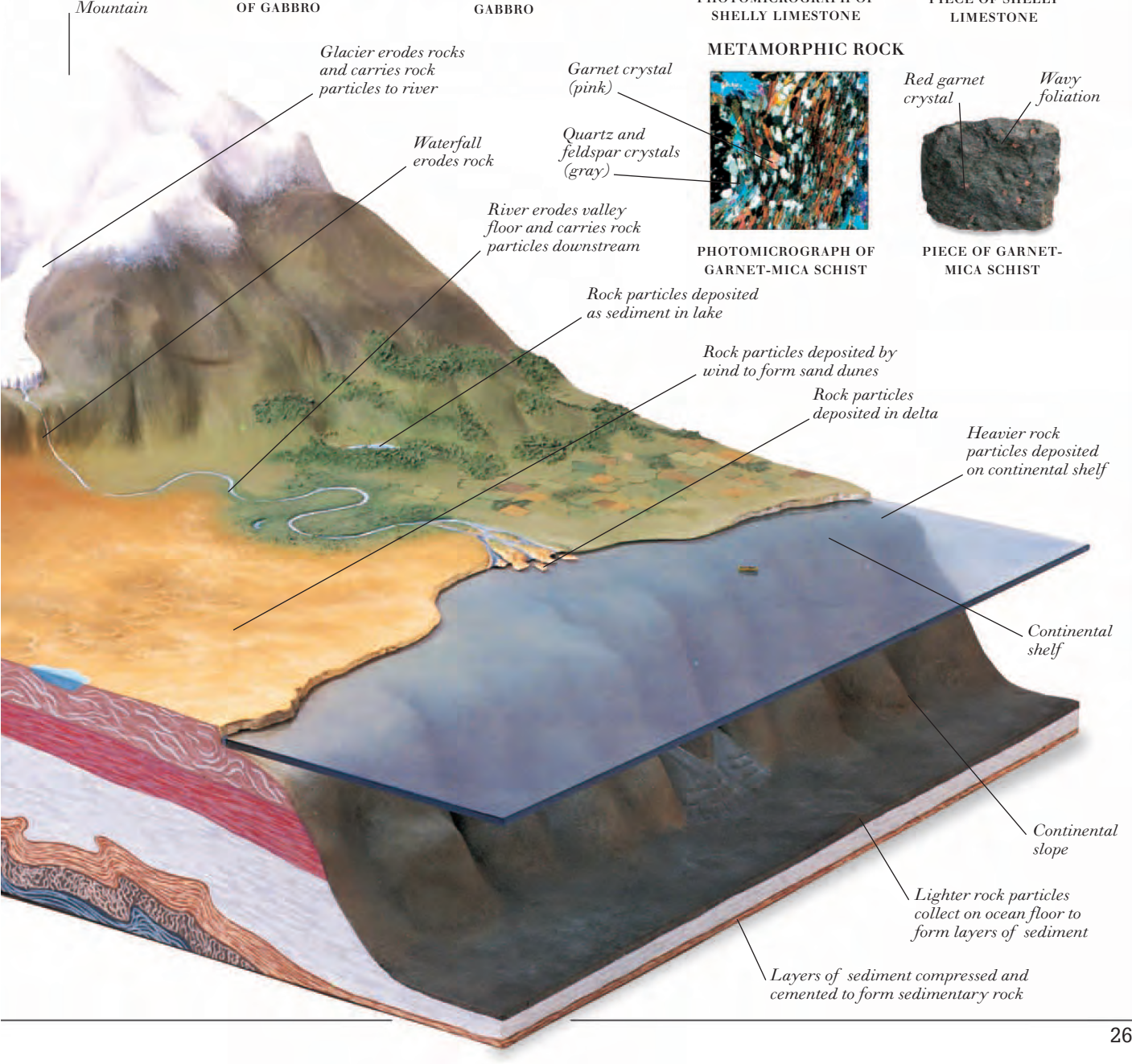


PIECE OF SHELLY LIMESTONE

METAMORPHIC ROCK

PHOTOMICROGRAPH OF GARNET-MICA SCHIST

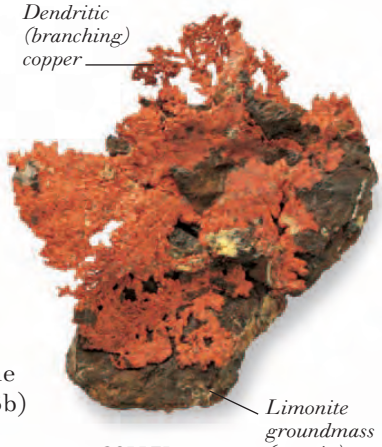
PIECE OF GARNET-MICA SCHIST



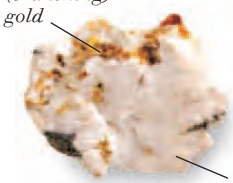
Minerals

A MINERAL IS A NATURALLY OCCURRING SUBSTANCE that has a characteristic chemical composition and specific physical properties, such as habit and streak (see pp. 270-271). A rock, by comparison, is an aggregate of minerals and need not have a specific chemical composition. Minerals are made up of elements (substances that cannot be broken down chemically into simpler substances), each of which can be represented by a chemical symbol. Minerals can be divided into two main groups: native elements and compounds. Native elements are made up of a pure element. Examples include gold (chemical symbol Au), silver (Ag), copper (Cu), and carbon (C); carbon occurs as a native element in two forms, diamond and graphite. Compounds are combinations of two or more elements. For example, sulfides are compounds of sulfur (S) and one or more other elements, such as lead (Pb) in the mineral galena, or antimony (Sb) in the mineral stibnite.

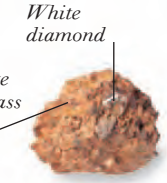
NATIVE ELEMENTS



COPPER
(Cu)



GOLD
(Au)



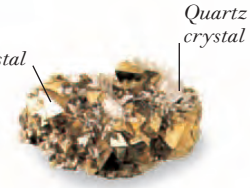
DIAMOND
(C)

GRAPHITE
(C)

SULFIDES

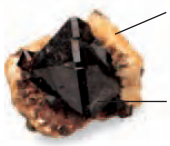
GALENA
(PbS)

STIBNITE
(Sb_2S_3)



PYRITES
(FeS_2)

OXIDES/HYDROXIDES

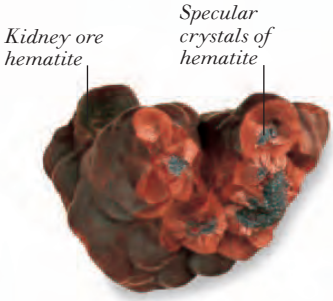


SMOKY QUARTZ
(SiO_2)

BAUXITE
($FeO(OH)$ and $Al_2O_5.2H_2O$)

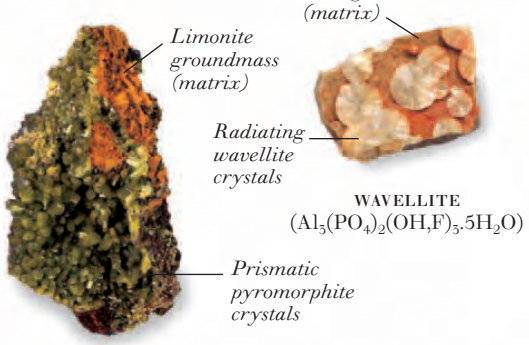
SPECULAR HEMATITE
(Fe_2O_5)

ONYX
(SiO_2)



KIDNEY ORE HEMATITE
(Fe_2O_5)

PHOSPHATES



WAVELLITE
$(Al_3(PO_4)_2(OH,F)_3.5H_2O)$

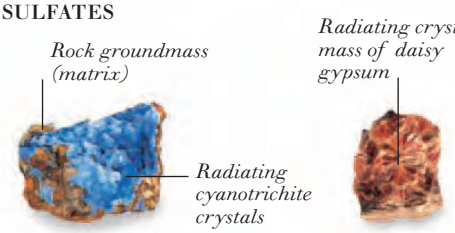
PYROMORPHITE
$(Pb_5(PO_4)_3Cl)$

CARBONATES

CERUSSITE
$(PbCO_3)$

CALCITE
$(CaCO_3)$

SULFATES



CYANOTRICHITE
$(Cu_4Al_2(SO_4)(OH)_{12}.2H_2O)$

DAISY GYPSUM
$(CaSO_4.2H_2O)$

MOLYBDATE

WULFENITE
$(PbMoO_4)$

SILICATES

SODALITE
$(Na_8Al_6Si_6O_{24}Cl_2)$

TOURMALINE
$(Na(Mg,Fe,Li,Mn,Al)_3Al_6(BO_3)_3Si_6.O_{18}(OH,F)_4)$

OLIVINE
$(Fe_2SiO_4 - Mg_2SiO_4)$

EPIDOTE
$(Ca_2(Al,Fe)_3(SiO_4)_3(OH))$

MUSCOVITE
$(KAl_2(Si_3Al)O_{10}(OH,F)_2)$

ORTHOCLASE
$(KAlSi_3O_8)$

HALIDES

GREEN FLUORITE
(CaF_2)

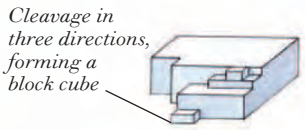
ORANGE HALITE (ROCK SALT)
$(NaCl)$

Mineral features

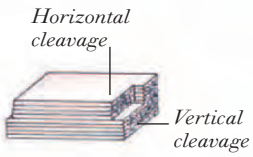
MINERALS CAN BE IDENTIFIED BY STUDYING features such as fracture, cleavage, crystal system, habit, hardness, color, and streak. Minerals can break in different ways. If a mineral breaks in an irregular way, leaving rough surfaces, it possesses fracture. If a mineral breaks along well-defined planes of weakness, it possesses cleavage. Specific minerals have distinctive patterns of cleavage; for example, mica cleaves along one plane. Most minerals form crystals, which can be categorized into crystal systems according to their symmetry and number of faces. Within each system, several different but related forms of crystal are possible; for example, a cubic crystal can have six, eight, or 12 sides. A mineral's habit is the typical form taken by an aggregate of its crystals. Examples of habit include botryoidal (like a bunch of grapes) and massive (no definite form). The relative hardness of a mineral may be assessed by testing its resistance to scratching. This property is usually measured using Mohs scale, which increases in hardness from 1 (talc) to 10 (diamond). The color of a mineral is not a dependable guide to its identity as some minerals have a range of colors. Streak (the color the powdered mineral makes when rubbed across an unglazed tile) is a more reliable indicator.

CLEAVAGE

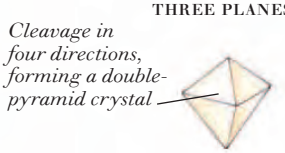
CLEAVAGE ALONG ONE PLANE



CLEAVAGE ALONG THREE PLANES

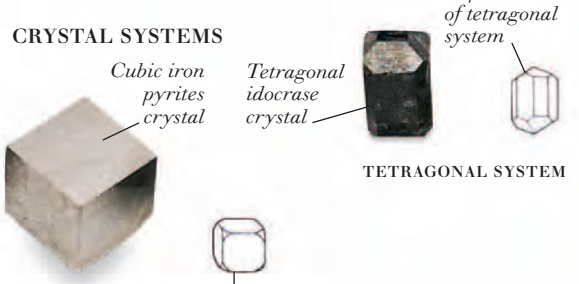


CLEAVAGE ALONG TWO PLANES



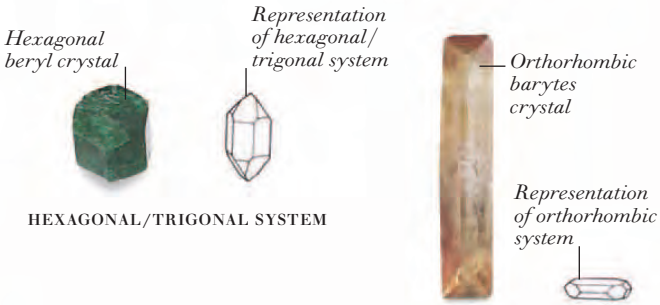
CLEAVAGE ALONG FOUR PLANES

CRYSTAL SYSTEMS



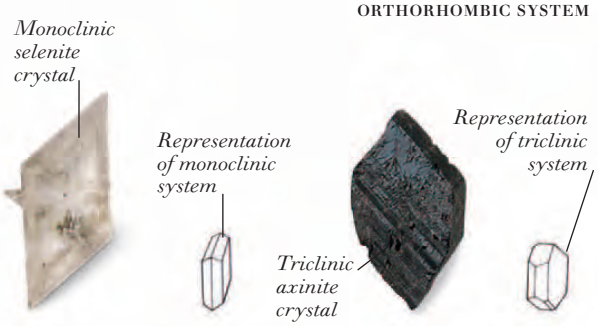
TETRAGONAL SYSTEM

CUBIC SYSTEM



HEXAGONAL/TRIGONAL SYSTEM

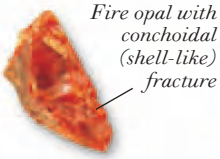
ORTHORHOMBIC SYSTEM



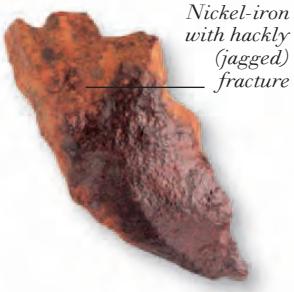
MONOCLINIC SYSTEM

TRICLINIC SYSTEM

FRACTURE



CONCHOIDAL FRACTURE

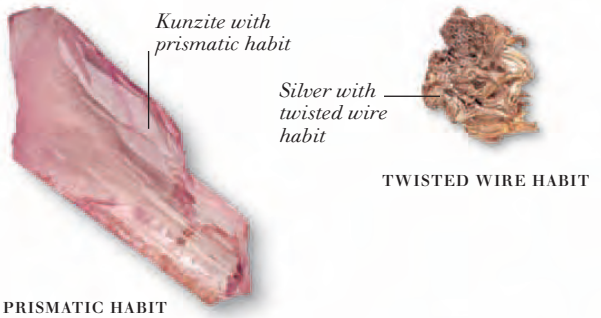


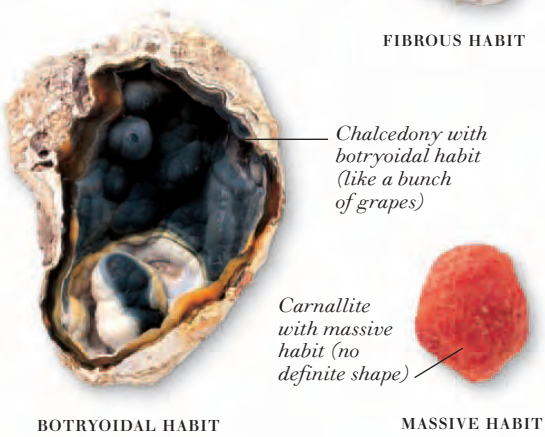
HACKLY FRACTURE

UNEVEN FRACTURE

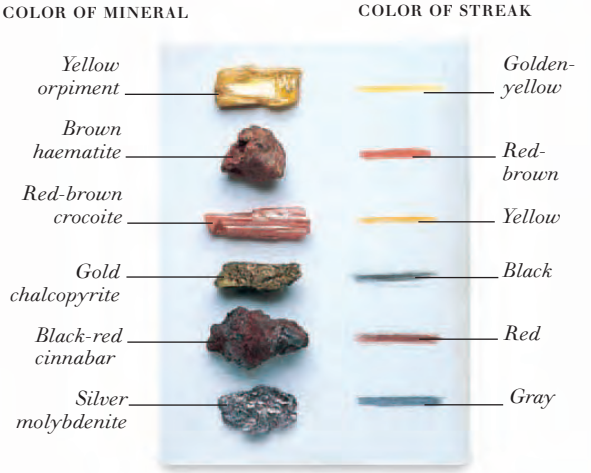
SPLINTERY FRACTURE

HABIT





STREAK



COLOR

MOHS SCALE OF HARDNESS

TALC	GYPSUM	CALCITE	FLUORITE	APATITE	ORTHOCLASE	QUARTZ	TOPAZ	CORUNDUM	DIAMOND
1	2	3	4	5	6	7	8	9	10

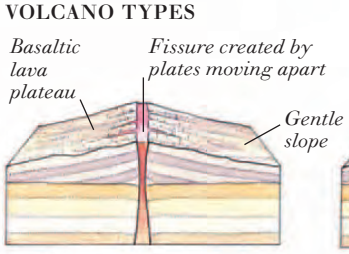
Volcanoes

PAHOEHOE (ROPY LAVA)

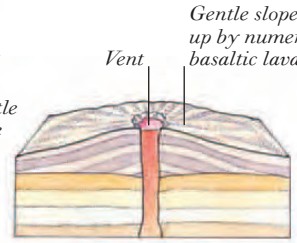
VOLCANOES ARE VENTS OR FISSURES in the Earth's crust through which magma (molten rock that originates from deep beneath the crust) is forced on to the surface as lava. They occur most commonly along the boundaries of crustal plates; most volcanoes lie in a belt called the "Ring of Fire," which runs along the edge of the Pacific Ocean. Volcanoes can be classified according to the violence and frequency of their eruptions. Nonexplosive volcanic eruptions generally occur where crustal plates pull apart. These eruptions produce runny basaltic lava that spreads quickly over a wide area to form relatively flat cones. The most violent eruptions take place where plates collide. Such eruptions produce thick rhyolitic lava and may also blast out clouds of dust and pyroclasts (lava fragments). The lava does not flow far before cooling and therefore builds up steep-sided, conical volcanoes. Some volcanoes produce lava and ash eruptions, which build up composite volcanic cones. Volcanoes that erupt frequently are described as active; those that erupt rarely are termed dormant; and those that have stopped erupting altogether are termed extinct. As well as the volcanoes themselves, other features associated with volcanic regions include geysers, hot mineral springs, solfataras, fumaroles, and bubbling mud pools.

HORU GEYSER, NEW ZEALAND

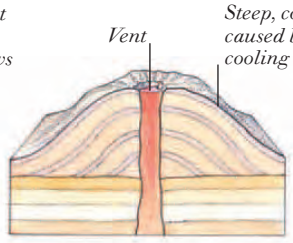
VOLCANO TYPES



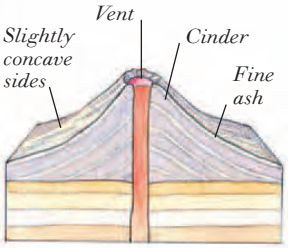
FISSURE VOLCANO



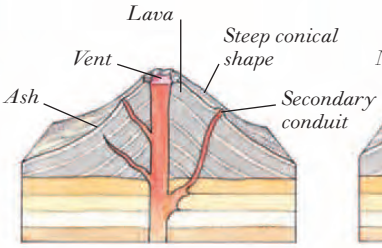
BASIC SHIELD VOLCANO



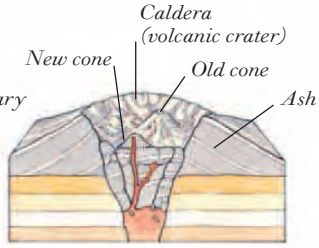
DOME VOLCANO



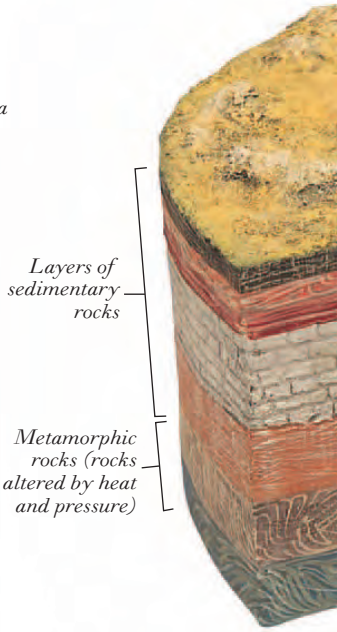
ASH-CINDER VOLCANO



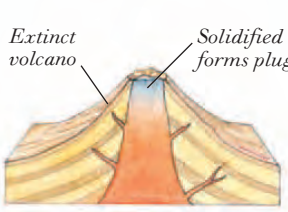
COMPOSITE VOLCANO



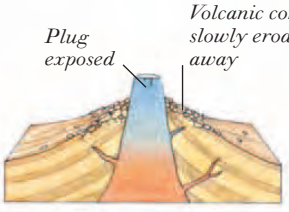
CALDERA VOLCANO



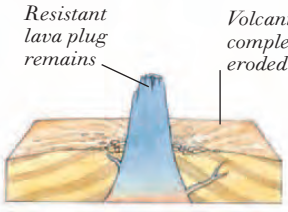
HOW VOLCANIC PLUGS BECOME EXPOSED



PLUG FORMATION



INITIAL EROSION AROUND PLUG



COMPLETE DENUDATION OF PLUG

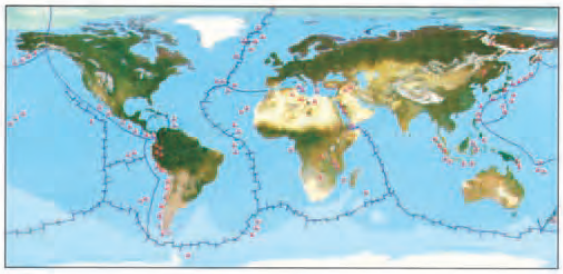
LAPILLI (LAVA FRAGMENTS)

TYPES OF LAVA

AA (BLOCKY LAVA)

REMELTED LAVA

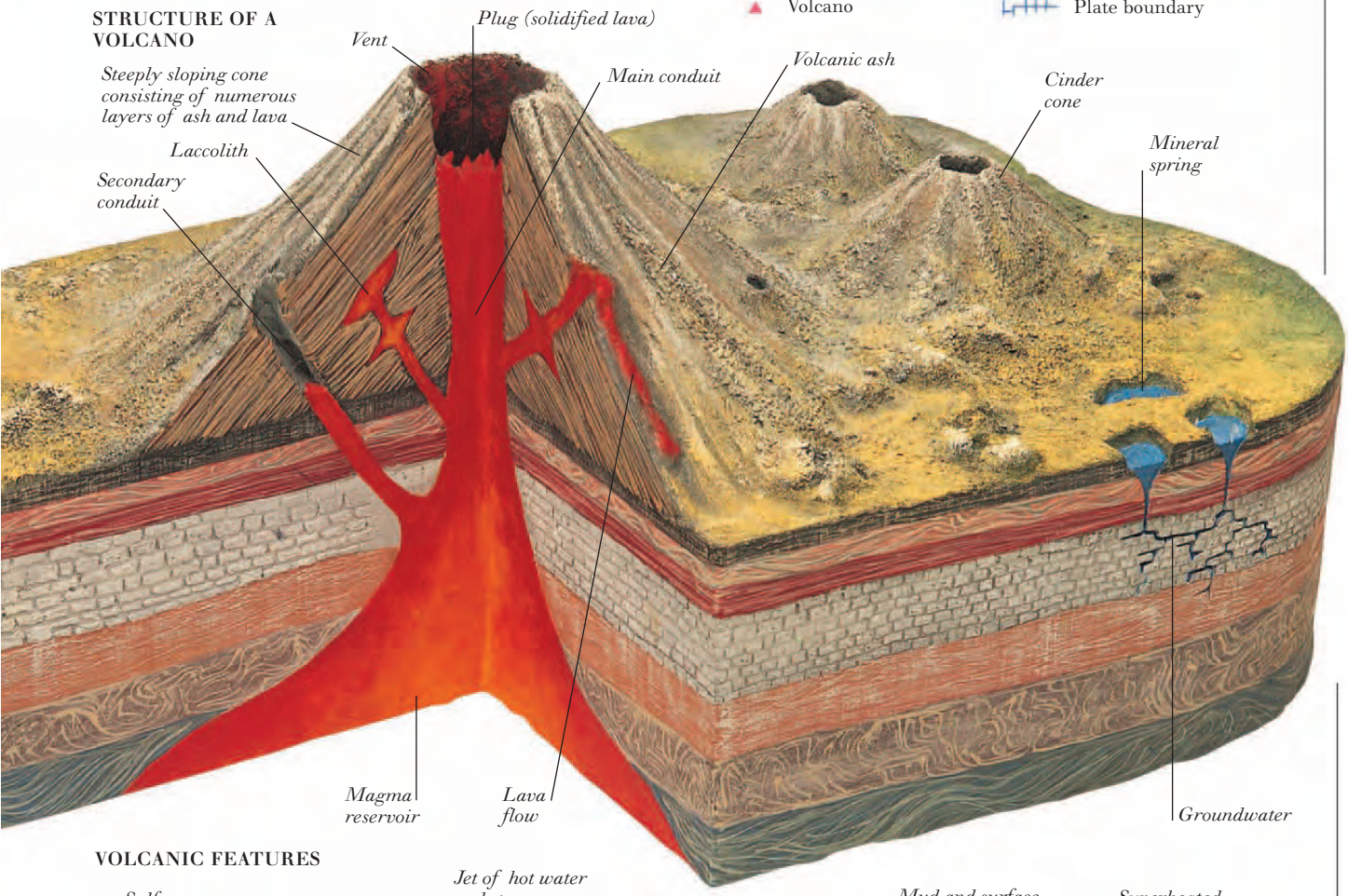
LOCATION OF VOLCANOES



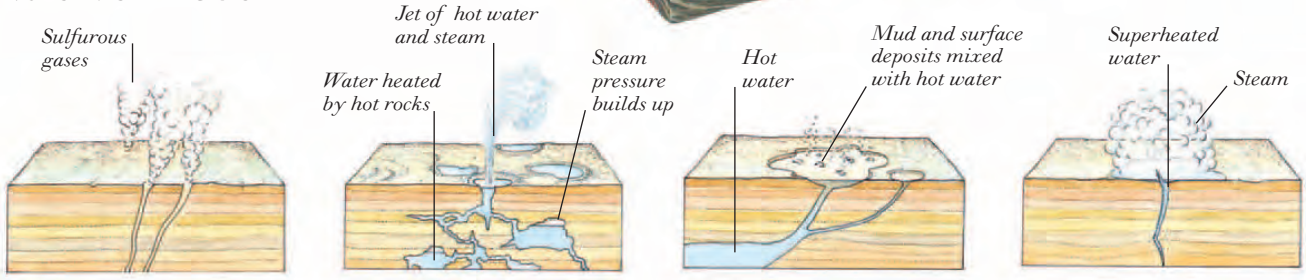
Volcano

Plate boundary

STRUCTURE OF A VOLCANO



VOLCANIC FEATURES



SOLFATARA

GEYSER

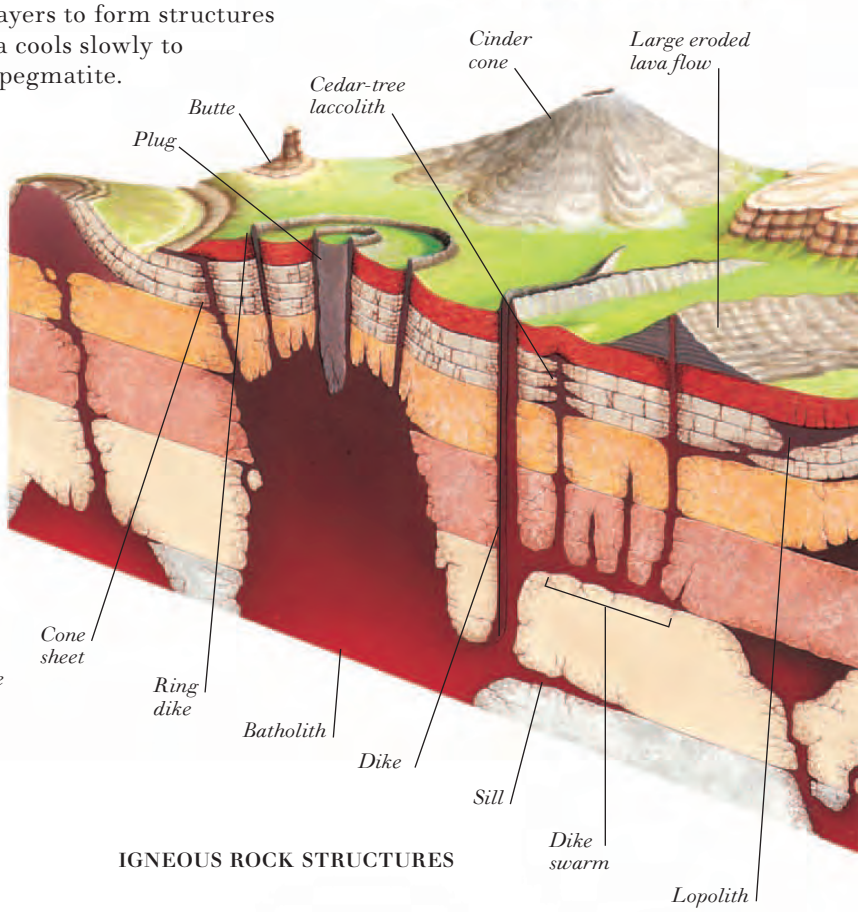
MUD POOL

FUMAROLE

Igneous and metamorphic rocks

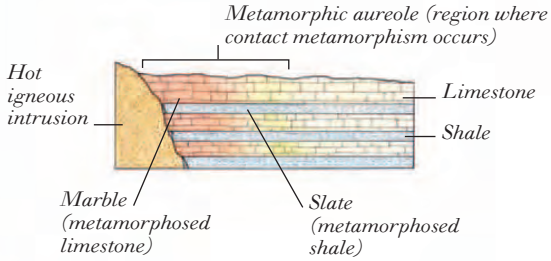
IGNEOUS ROCKS ARE FORMED WHEN MAGMA (molten rock that originates from deep beneath the Earth's crust) cools and solidifies. There are two main types of igneous rock: intrusive and extrusive. Intrusive rocks are formed deep underground where magma is forced into cracks or between rock layers to form structures such as sills, dikes, and batholiths. The magma cools slowly to form coarse-grained rocks such as gabbro and pegmatite. Extrusive rocks are formed above the Earth's surface from lava (magma that has been ejected in a volcanic eruption). The molten lava cools quickly, producing fine-grained rocks such as rhyolite and basalt. Metamorphic rocks are those that have been altered by intense heat (contact metamorphism) or extreme pressure (regional metamorphism). Contact metamorphism occurs when rocks are changed by heat from, for example, an igneous intrusion or lava flow. Regional metamorphism occurs when rock is crushed in the middle of a folding mountain range. Metamorphic rocks can be formed from igneous rocks, sedimentary rocks, or even from other metamorphic rocks.

BASALT COLUMNS

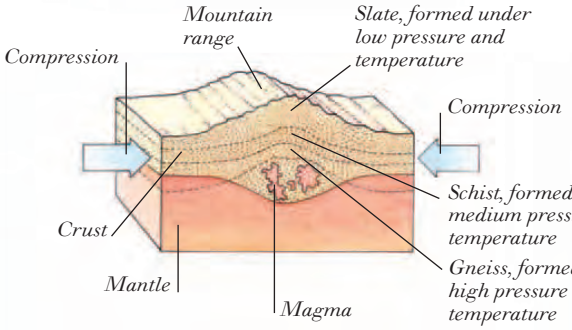


IGNEOUS ROCK STRUCTURES

CONTACT METAMORPHISM



REGIONAL METAMORPHISM

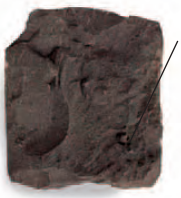


EXAMPLES OF METAMORPHIC ROCKS

GNEISS FOLDED SCHIST SKARN

EXAMPLES OF EXTRUSIVE IGNEOUS ROCKS

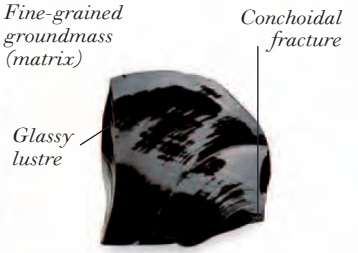
RHYOLITE



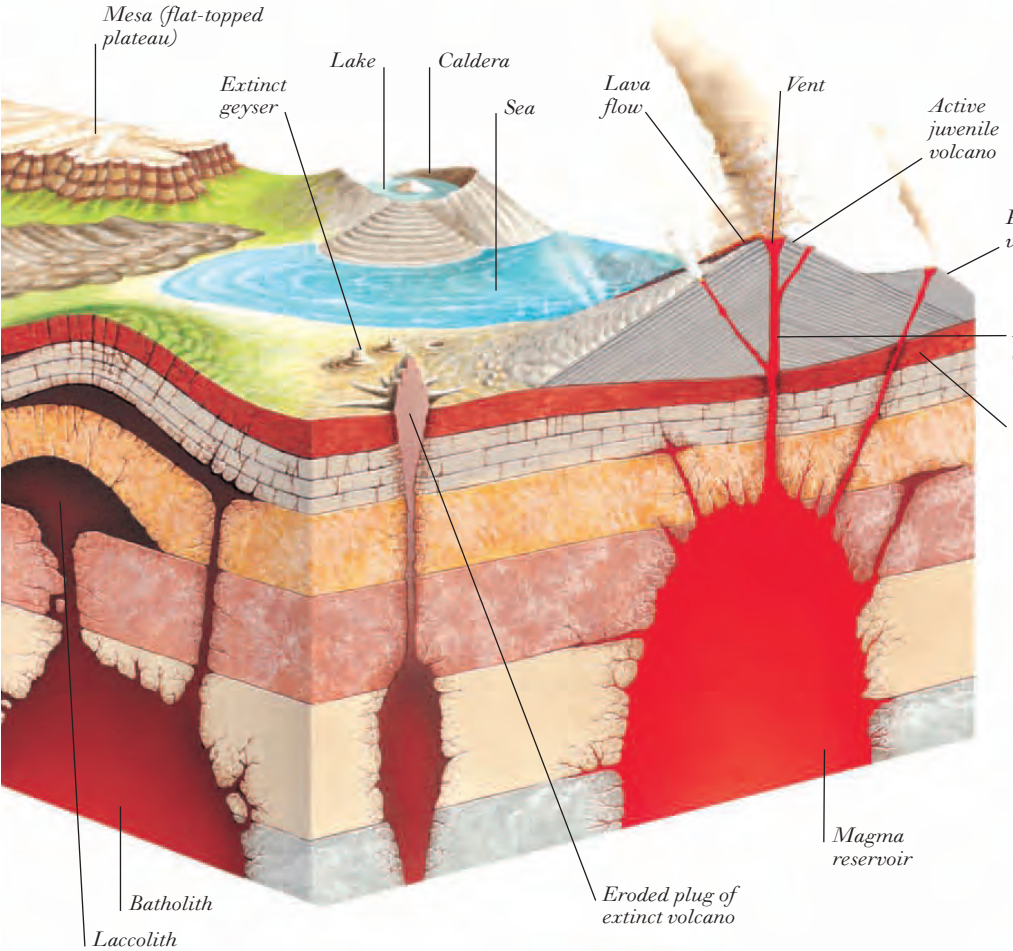
BASALT

PUMICE

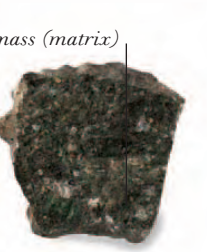
PORPHYRITIC ANDESITE



OBSIDIAN

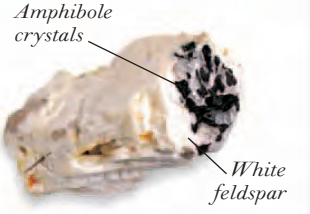


EXAMPLES OF INTRUSIVE IGNEOUS ROCKS



KIMBERLITE

OLIVINE GABBRO



FELDSPAR PEGMATITE

SLATE WITH PYRITES

CHIASTOLITE HORNFELS

GREEN MARBLE

HALLEFLINTA

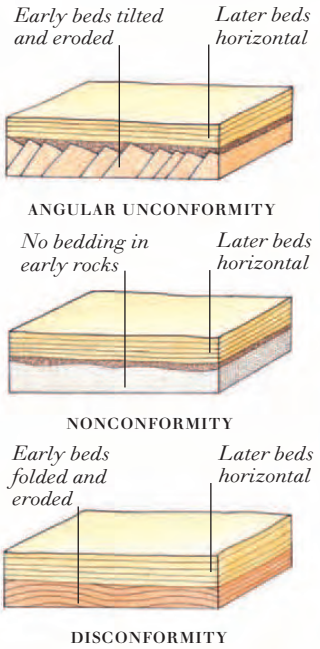
SYENITE

Sedimentary rocks

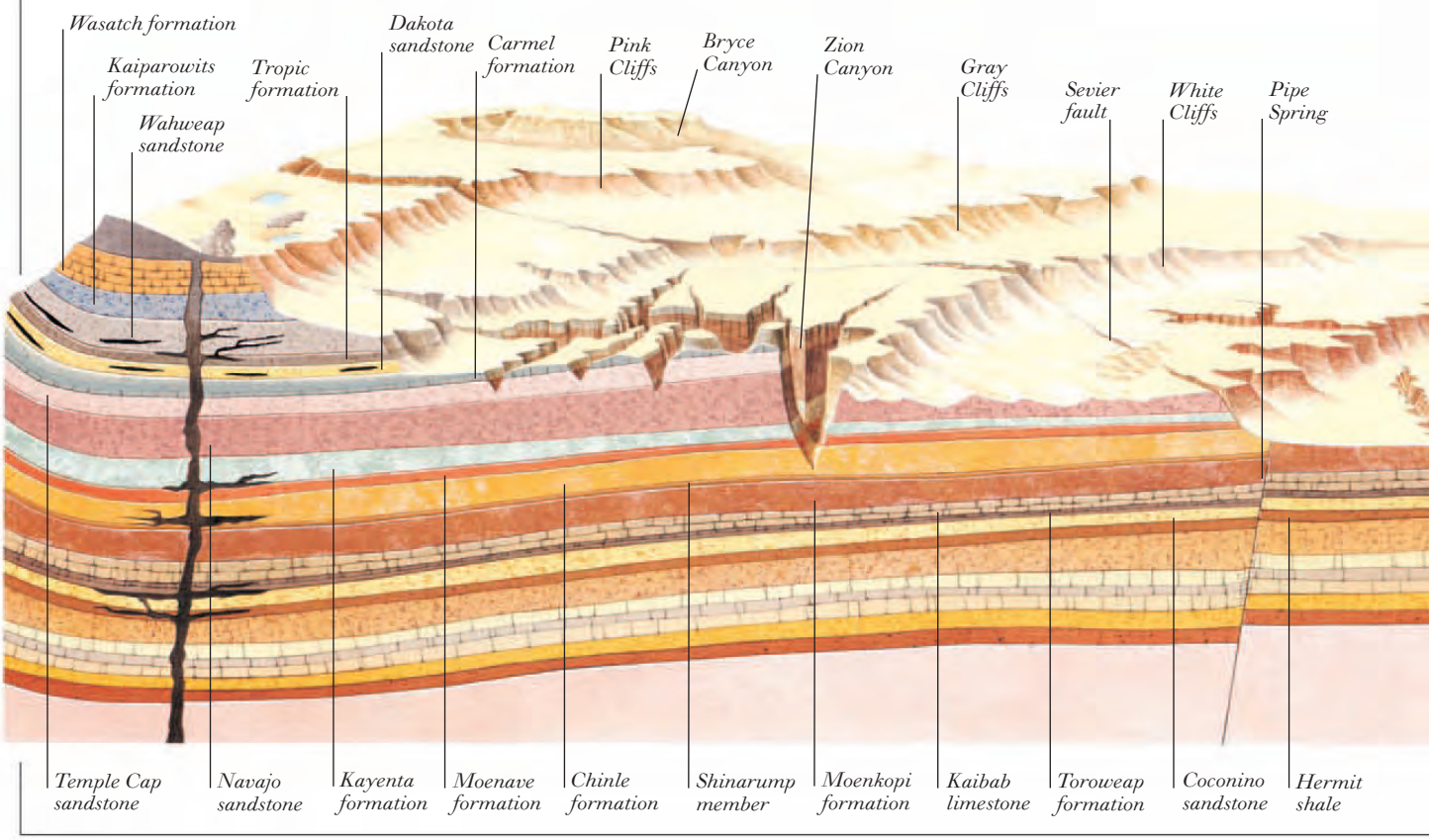
SEDIMENTARY ROCKS ARE FORMED BY THE ACCUMULATION and consolidation of sediments (see pp. 266-267). There are three main types of sedimentary rock. Clastic sedimentary rocks, such as breccia or sandstone, are formed from other rocks that have been broken down into fragments by weathering (see pp. 282-283), which have then been transported and deposited elsewhere. Organic sedimentary rocks—for example, coal (see pp. 280-281)—are derived from plant and animal remains. Chemical sedimentary rocks are formed by chemical processes. For example, rock salt is formed when salt dissolved in water is deposited as the water evaporates. Sedimentary rocks are laid down in layers, called beds or strata. Each new layer is laid down horizontally over older ones. There are usually some gaps in the sequence, called unconformities. These represent periods in which no new sediments were being laid down, or when earlier sedimentary layers were raised above sea level and eroded away.

THE GRAND CANYON, USA

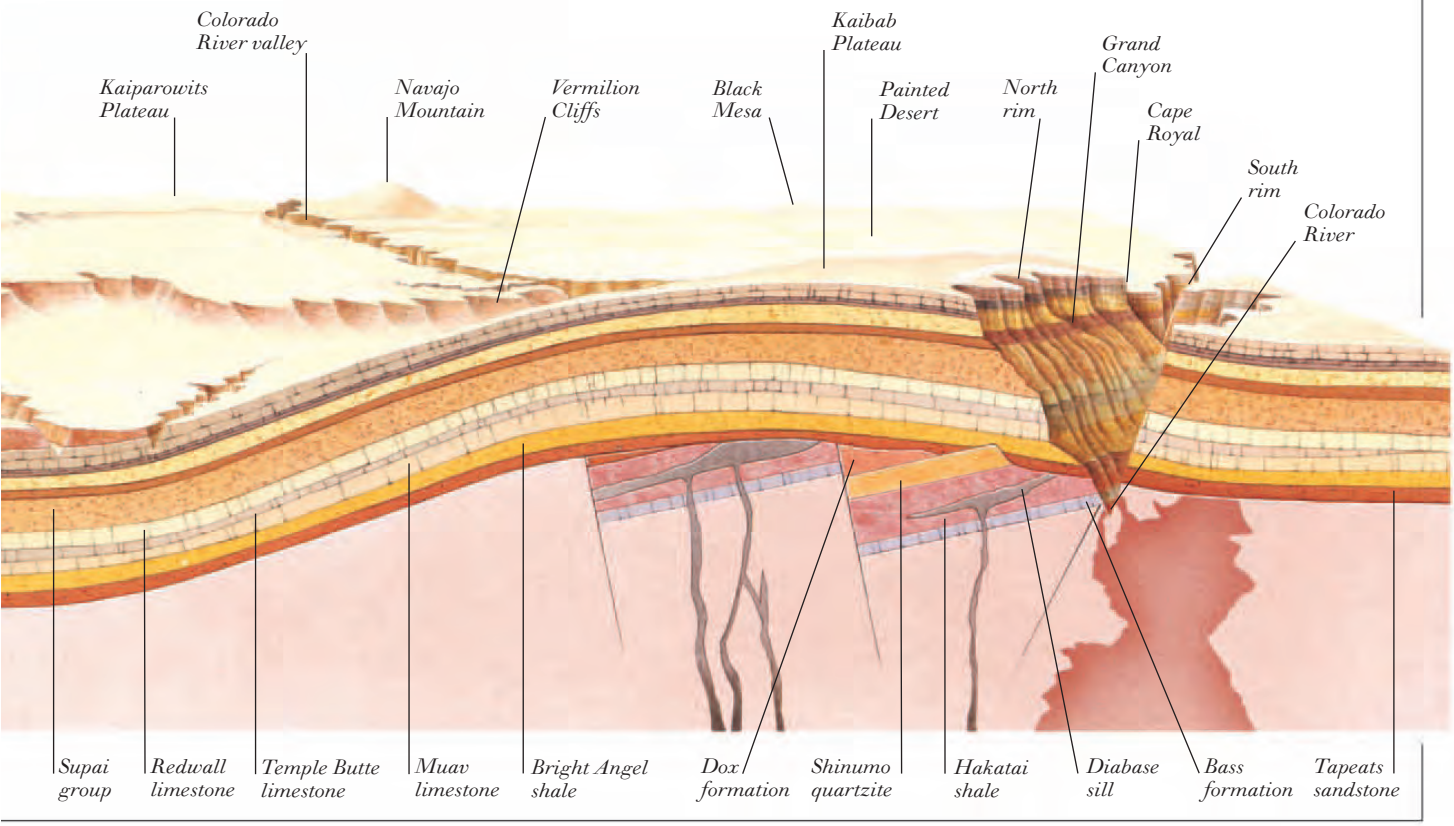
EXAMPLES OF UNCONFORMITIES



SEDIMENTARY LAYERS OF THE GRAND CANYON REGION



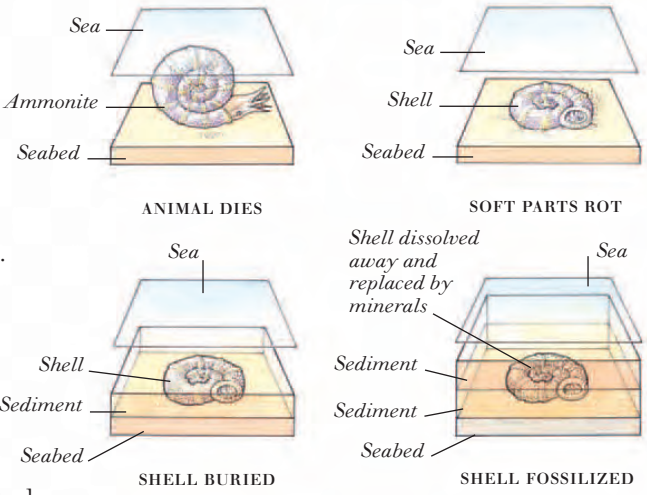
EXAMPLES OF SEDIMENTARY ROCKS



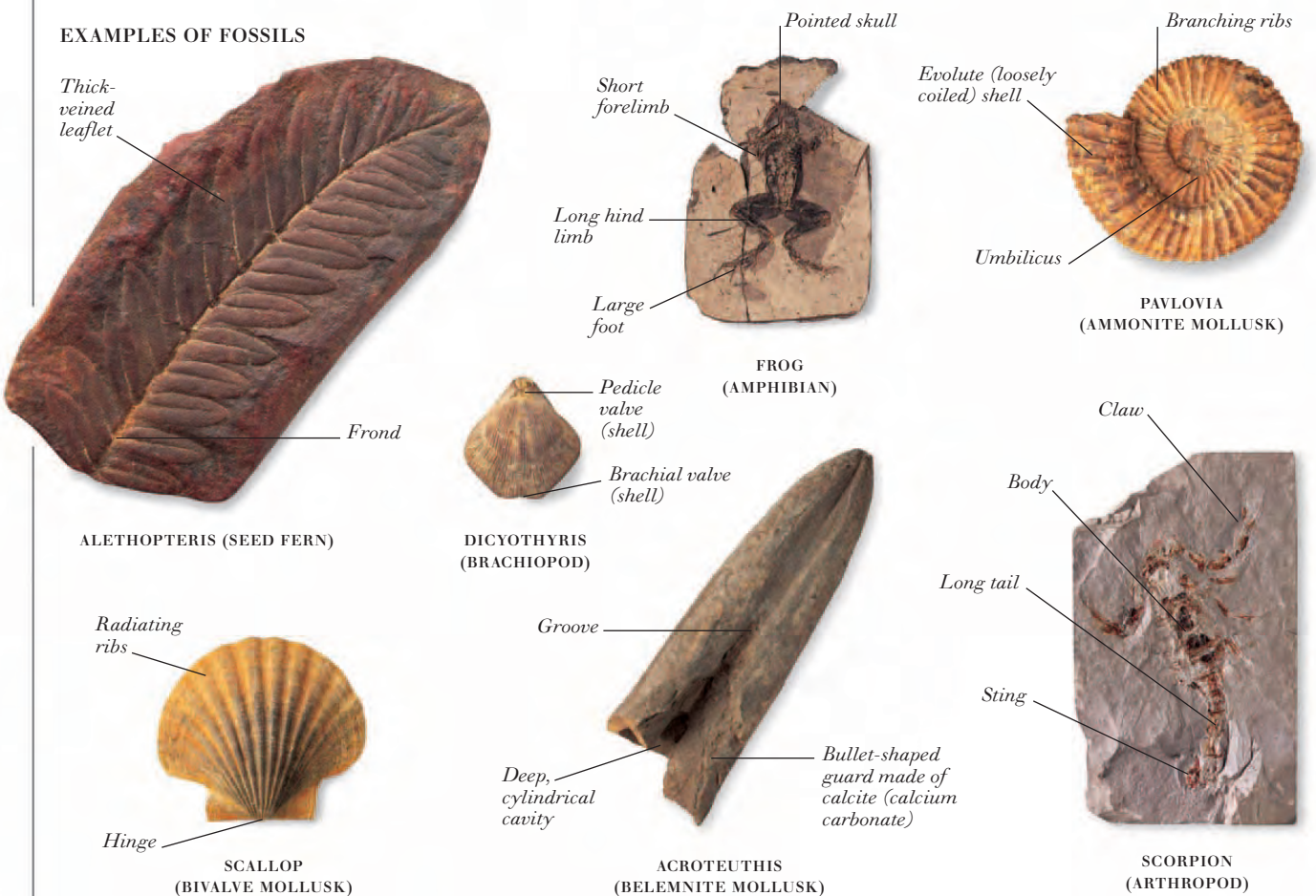
Fossils

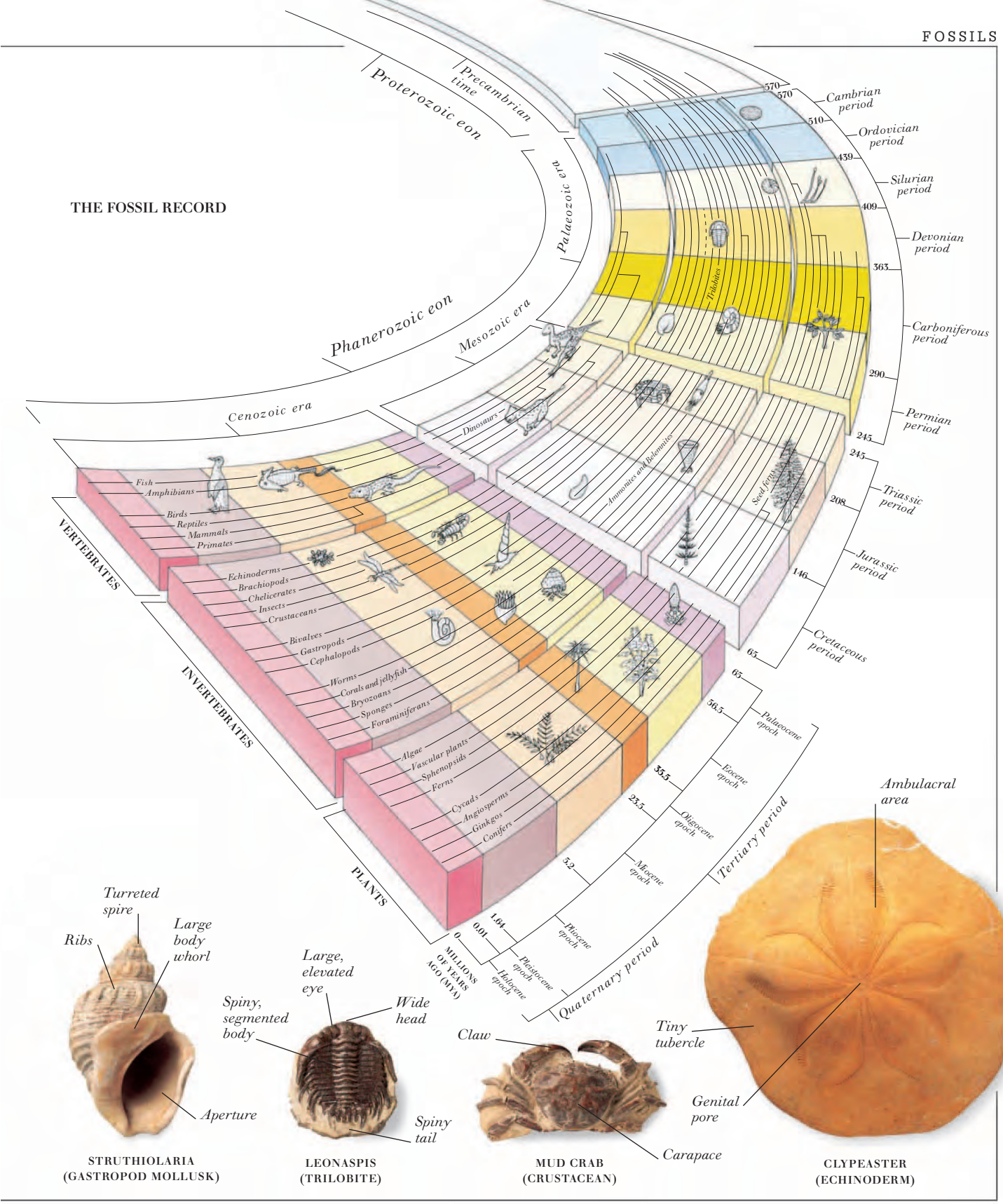
FOSSILS ARE THE REMAINS of plants and animals that have been preserved in rock. A fossil may be the preserved remains of an organism itself, an impression of it in rock, or preserved traces (known as trace fossils) left by an organism while it was alive, such as organic carbon outlines, fossilized footprints, or droppings. Most dead organisms soon rot away or are eaten by scavengers. For fossilization to occur, rapid burial by sediment is necessary. The organism decays, but the harder parts—bones, teeth, and shells, for example—may be preserved and hardened by minerals from the surrounding sediment. Fossilization may also occur even when the hard parts of an organism are dissolved away to leave an impression called a mold. The mold is filled by minerals, thereby creating a cast of the organism. The study of fossils (paleontology) can not only show how living things have evolved, but can also help to reveal the Earth's geological history—for example, by aiding in the dating of rock strata.

PROCESS OF FOSSILIZATION



EXAMPLES OF FOSSILS




THE FOSSIL RECORD
Precambrian time
Proterozoic eon
Palaeozoic era
Phanerozoic eon
Mesozoic era
Cenozoic era
570
570
Cambrian period
510
Ordovician period
439
Silurian period
409
Devonian period
363
Carboniferous period
290
Permian period
245
245
Triassic period
208
Jurassic period
146
Cretaceous period
65
65
56.5
Palaeocene epoch
Eocene epoch
35.5
23.5
Oligocene epoch
Miocene epoch
5.2
Pliocene epoch
1.64
0.01
0
Pleistocene epoch
Holocene epoch
MILLIONS OF YEARS AGO (MYA)
Tertiary period
Quaternary period
Trilobites
Dinosaurs
Ammonites and belemnites
Seed ferns
VERTEBRATES
Fish
Amphibians
Birds
Reptiles
Mammals
Primates
INVERTEBRATES
Echinoderms
Brachiopods
Chelicerates
Insects
Crustaceans
Bivalves
Gastropods
Cephalopods
Worms
Corals and jellyfish
Bryozoans
Sponges
Foraminiferans
PLANTS
Algae
Vascular plants
Sphenopsids
Ferns
Cycads
Angiosperms
Ginkgos
Conifers
Turreted spire
Ribs
Large body whorl
Aperture
STRUTHIOLARIA (GASTROPOD MOLLUSK)
Large, elevated eye
Wide head
Spiny, segmented body
Spiny tail
LEONASPIS (TRILOBITE)
Claw
Carapace
MUD CRAB (CRUSTACEAN)
Ambulacral area
Tiny tubercle
Genital pore
CLYPEASTER (ECHINODERM)

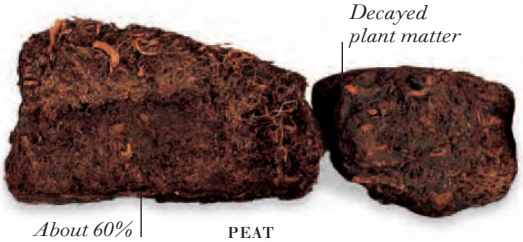
Mineral resources

MINERAL RESOURCES CAN BE DEFINED AS naturally occurring substances that can be extracted from the Earth and are useful as fuels and raw materials. Coal, oil, and gas – collectively called fossil fuels – are commonly included in this group, but are not strictly minerals, because they are of organic origin. Coal formation begins when vegetation is buried and partly decomposed to form peat. Overlying sediments compress the peat and transform it into lignite (soft brown coal). As the overlying sediments accumulate, increasing pressure and temperature eventually transform the lignite into bituminous and hard anthracite coals. Oil and gas are usually formed from organic matter that was deposited in marine sediments. Under the effects of heat and pressure, the compressed organic matter undergoes complex chemical changes to form oil and gas. The oil and gas percolate upwards through water-saturated, permeable rocks and they may rise to the Earth's surface or accumulate below an impermeable layer of rock that has been folded or faulted to form a trap – an anticline (upfold) trap, for example. Minerals are inorganic substances that may consist of a single chemical element, such as gold, silver, or copper, or combinations of elements (see pp. 268-269). Some minerals are concentrated in mineralization zones in rock associated with crustal movements or volcanic activity. Others may be found in sediments as placer deposits – accumulations of high-density minerals that have been weathered out of rocks, transported, and deposited (on riverbeds, for example).

OIL RIG, NORTH SEA

STAGES IN THE FORMATION OF COAL

PLANT MATTER



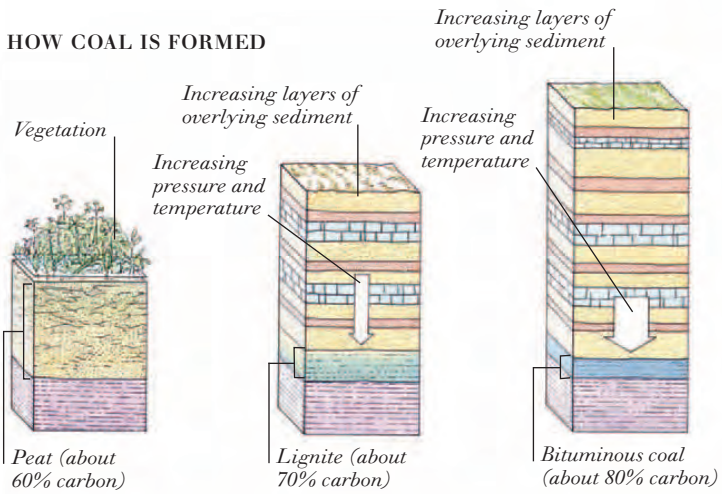
PEAT

LIGNITE (BROWN COAL)

BITUMINOUS COAL

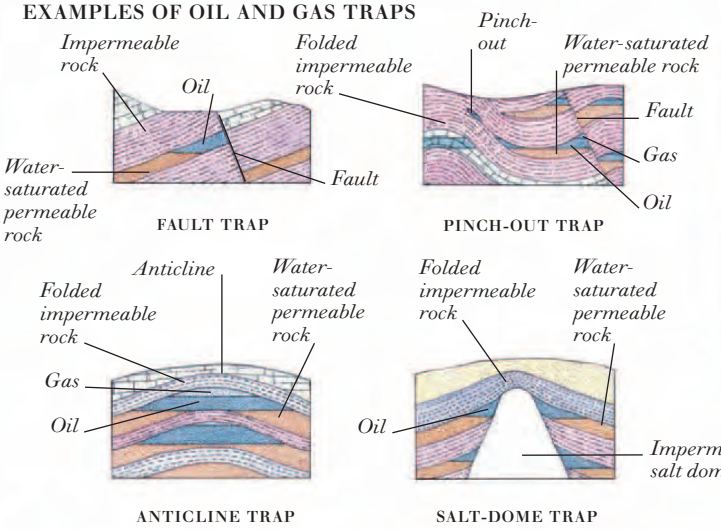
ANTHRACITE COAL

HOW COAL IS FORMED

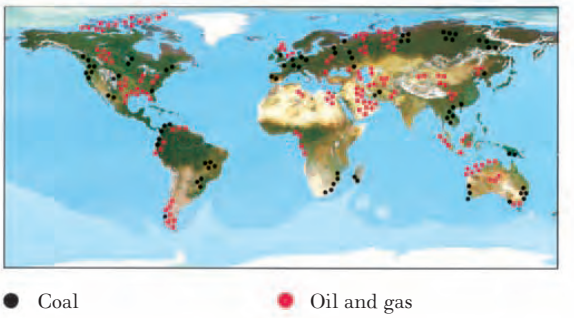


PEAT | LIGNITE (BROWN COAL) | BITUMINOUS COAL

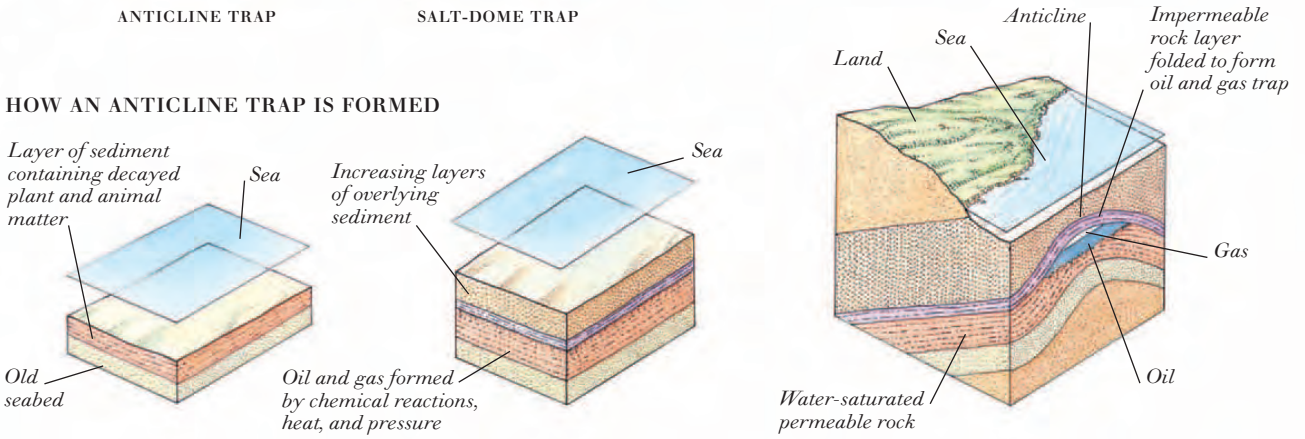
EXAMPLES OF OIL AND GAS TRAPS



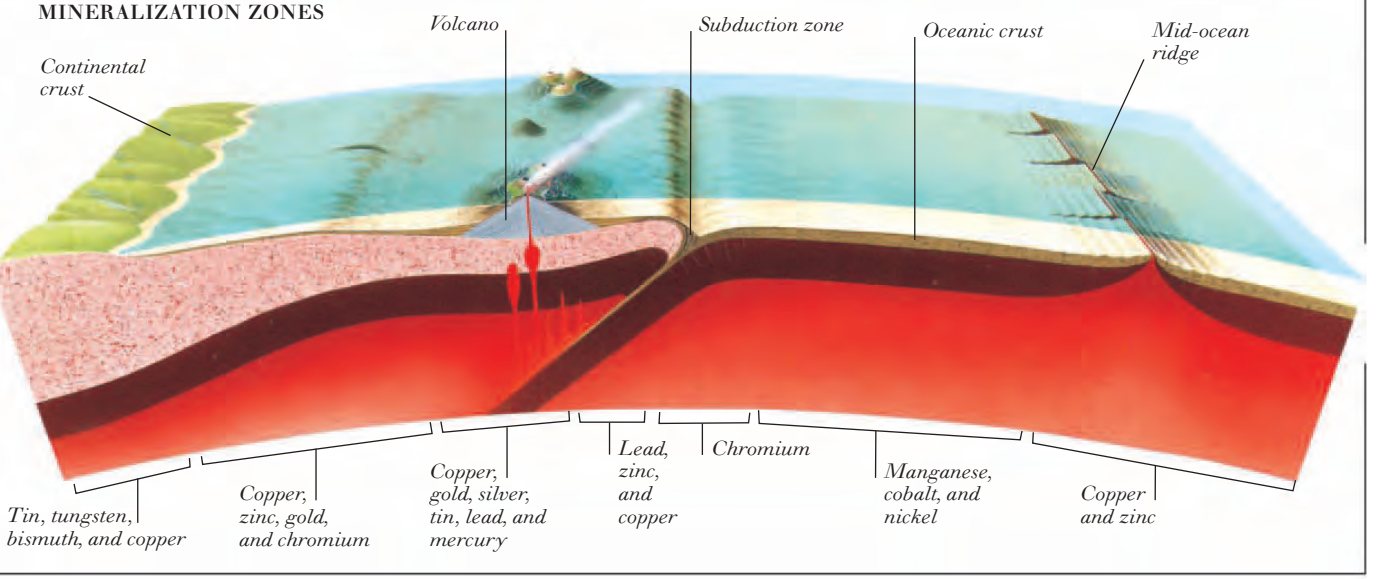
MAJOR COAL, OIL, AND GAS DEPOSITS



HOW AN ANTICLINE TRAP IS FORMED



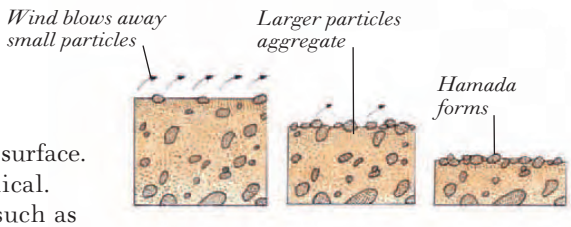
MINERALIZATION ZONES



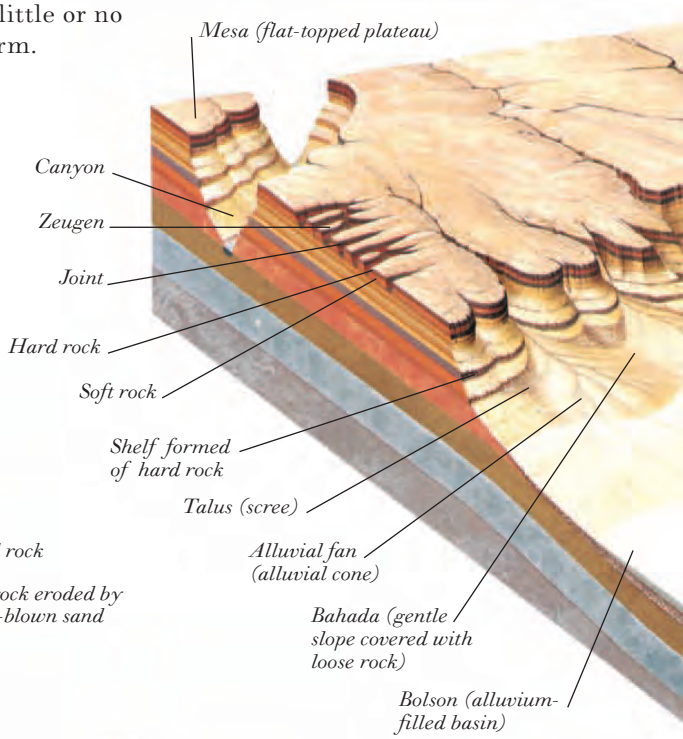
Weathering and erosion

WEATHERING IS THE BREAKING DOWN of rocks on the Earth's surface. There are two main types: physical (or mechanical) and chemical. Physical weathering may be caused by temperature changes, such as freezing and thawing, or by abrasion from material carried by winds, rivers, or glaciers. Rocks may also be broken down by the actions of animals and plants, such as the burrowing of animals and the growth of roots. Chemical weathering causes rocks to decompose by changing their chemical composition—for example, rainwater may dissolve certain minerals in a rock. Erosion is the wearing away and removal of land surfaces by water, wind, or ice. It is greatest in areas of little or no surface vegetation, such as deserts, where sand dunes may form.

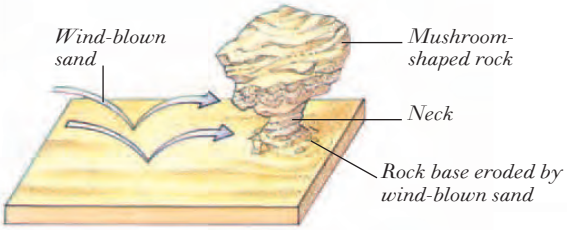
FORMATION OF A HAMADA (ROCK PAVEMENT)



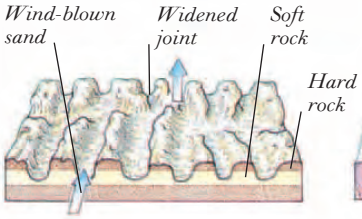
FEATURES OF WEATHERING AND EROSION



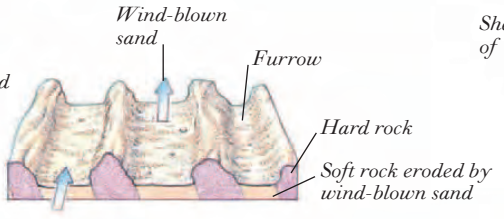
FEATURES PRODUCED BY WIND ACTION



ROCK PEDESTAL

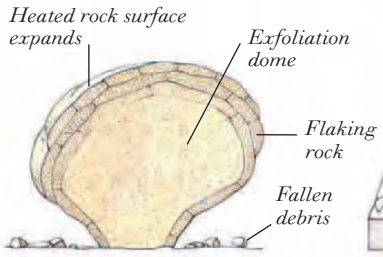


ZEUGEN

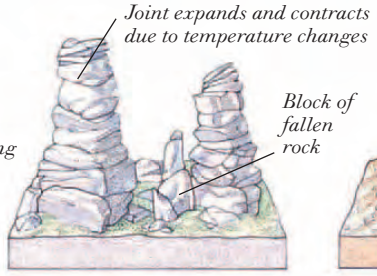


YARDANG

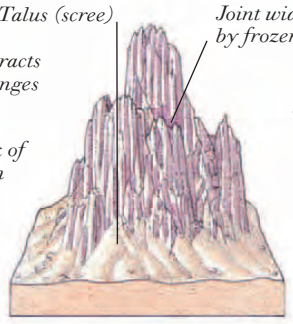
EXAMPLES OF PHYSICAL WEATHERING PROCESSES



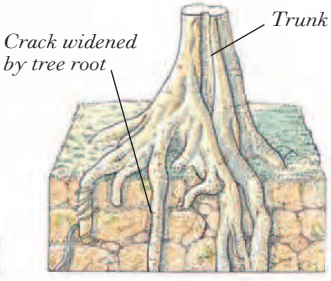
EXFOLIATION (ONION-SKIN WEATHERING)



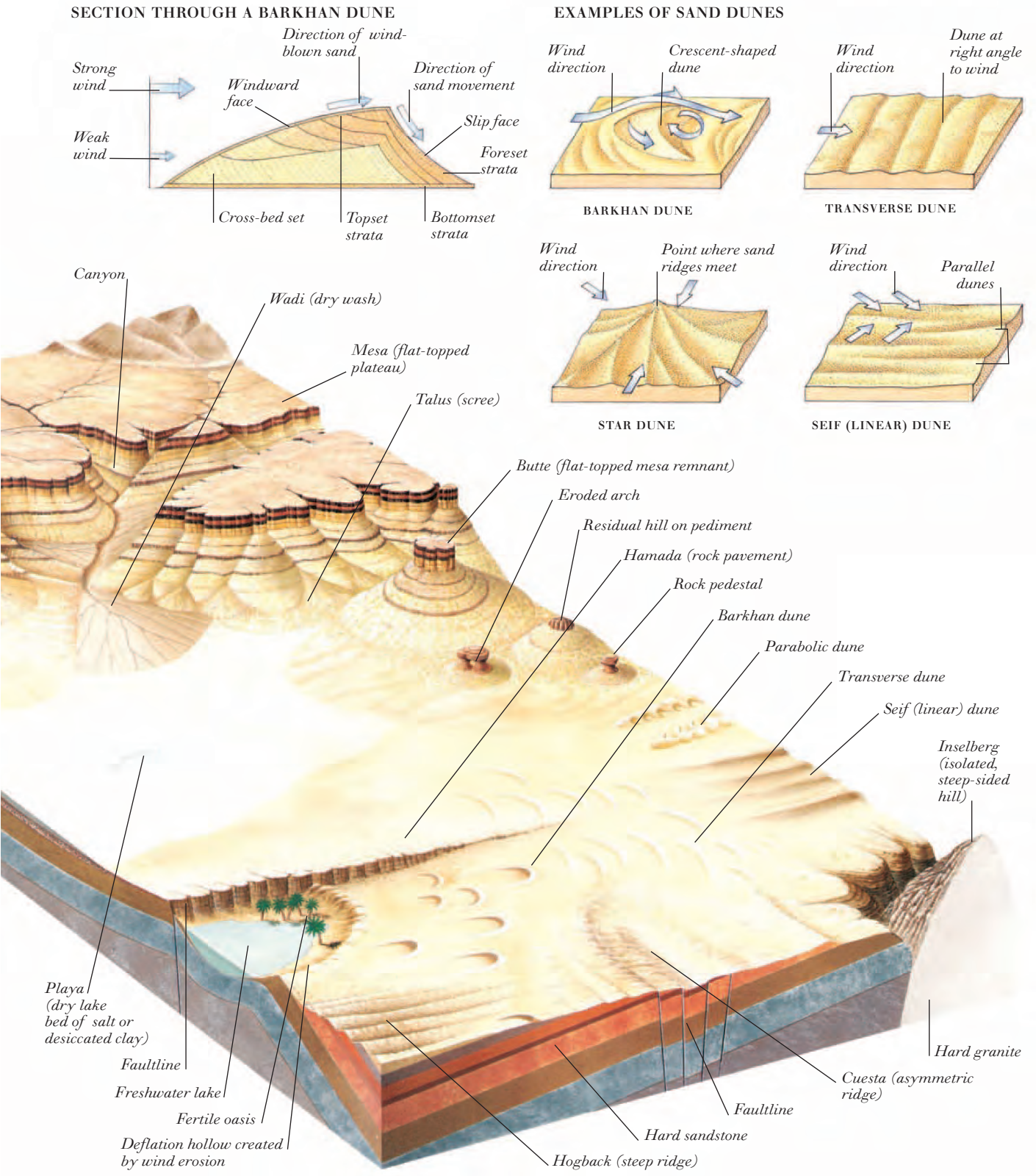
BLOCK DISINTEGRATION



FROST WEDGING



TREE ROOT ACTION


SECTION THROUGH A BARKHAN DUNE
Direction of wind-blown sand
Strong wind
Windward face
Direction of sand movement
Slip face
Weak wind
Foreset strata
Cross-bed set
Topset strata
Bottomset strata
EXAMPLES OF SAND DUNES
Wind direction
Crescent-shaped dune
BARKHAN DUNE
Wind direction
Dune at right angle to wind
TRANSVERSE DUNE
Wind direction
Point where sand ridges meet
STAR DUNE
Wind direction
Parallel dunes
SEIF (LINEAR) DUNE
Canyon
Wadi (dry wash)
Mesa (flat-topped plateau)
Talus (scree)
Butte (flat-topped mesa remnant)
Eroded arch
Residual hill on pediment
Hamada (rock pavement)
Rock pedestal
Barkhan dune
Parabolic dune
Transverse dune
Seif (linear) dune
Inselberg (isolated, steep-sided hill)
Playa (dry lake bed of salt or desiccated clay)
Faultline
Freshwater lake
Fertile oasis
Deflation hollow created by wind erosion
Hogback (steep ridge)
Hard sandstone
Faultline
Cuesta (asymmetric ridge)
Hard granite

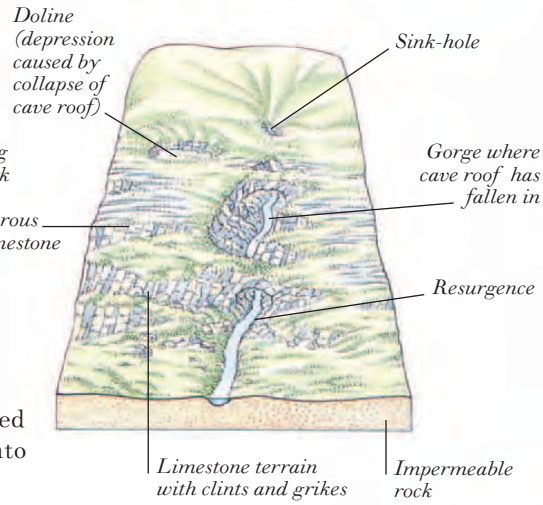
Caves

CAVES COMMONLY FORM in areas of limestone, although on coastlines they also occur in other rocks. Limestone is made of calcite (calcium carbonate), which dissolves in the carbonic acid naturally present in rainwater, and in humic acids from the decay of vegetation. The acidic water trickles down through cracks and joints in the limestone and between rock layers, breaking up the surface terrain into clints (blocks of rock), separated by grikes (deep cracks), and punctuated by sink-holes (also called swallow-holes or potholes) into which surface streams may disappear. Underground, the acidic water dissolves the rock around crevices, opening up a network of passages and caves, which can become large caverns if the roofs collapse. Various features are formed when the dissolved calcite is redeposited; for example, it may be redeposited along an underground stream to form a gour (series of calcite ridges), or in caves and passages to form stalactites and stalagmites. Stalactites develop where calcite is left behind as water drips from the roof; where the drops land, stalagmites build up.

MERGED STALACTITES

STALACTITE WITH RING MARKS

SURFACE TOPOGRAPHY OF A CAVE SYSTEM

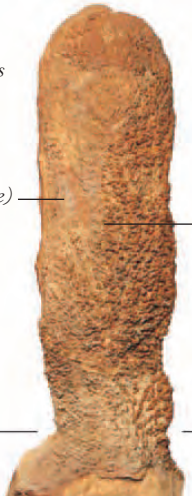


STALAGMITE FORMATIONS

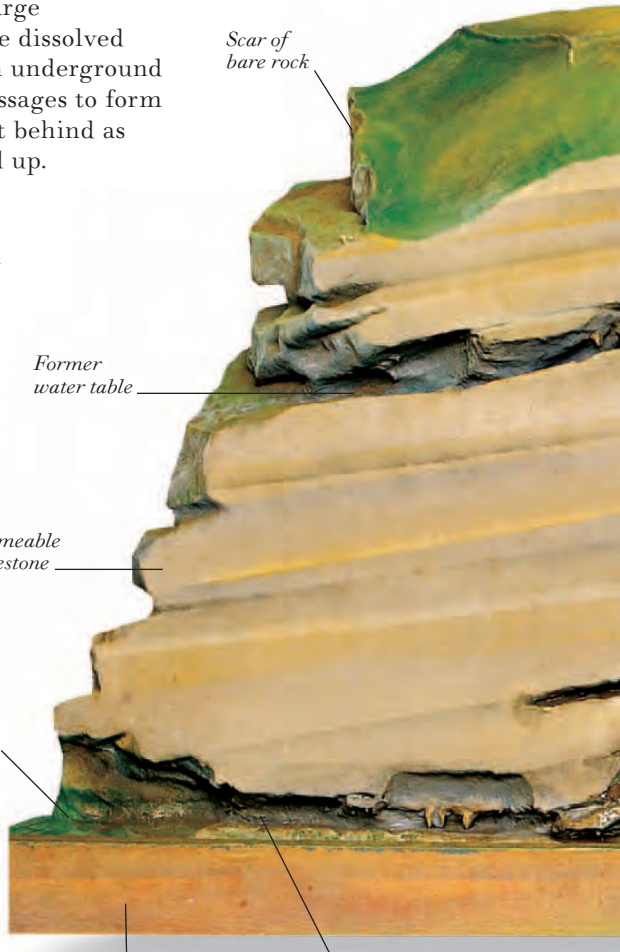
CRYSTALLINE STALAGMITIC FLOOR

CALCAREOUS TUFA

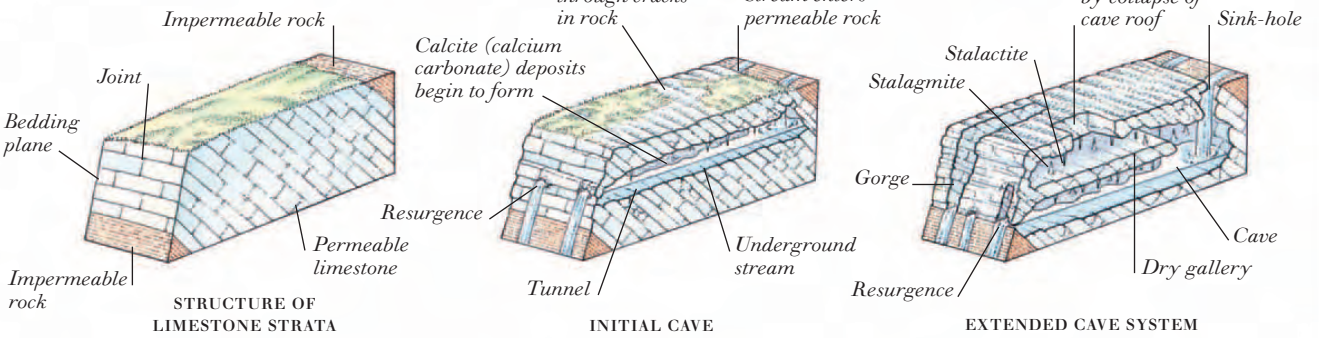
STALAGMITIC FLOOR



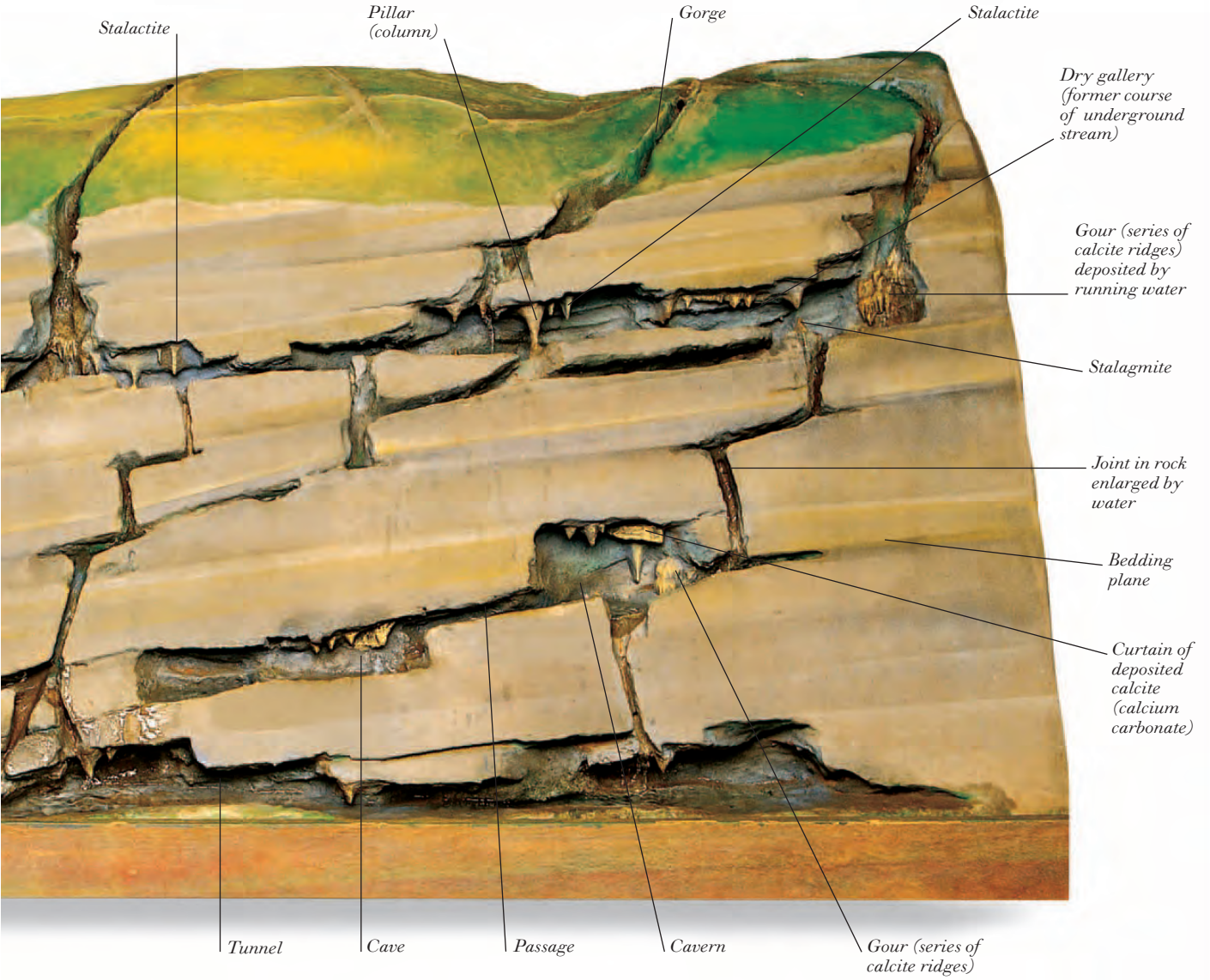
STALAGMITIC BOSS



DEVELOPMENT OF A CAVE SYSTEM



INTERCONNECTED CAVE SYSTEM

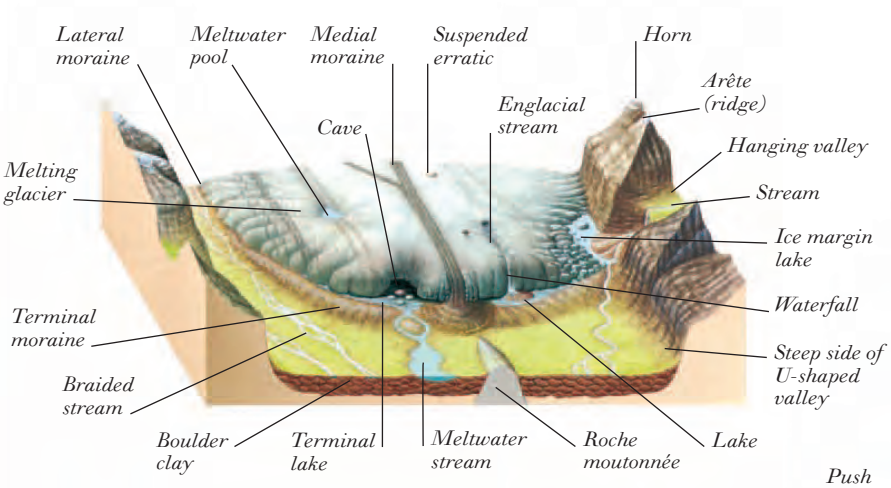


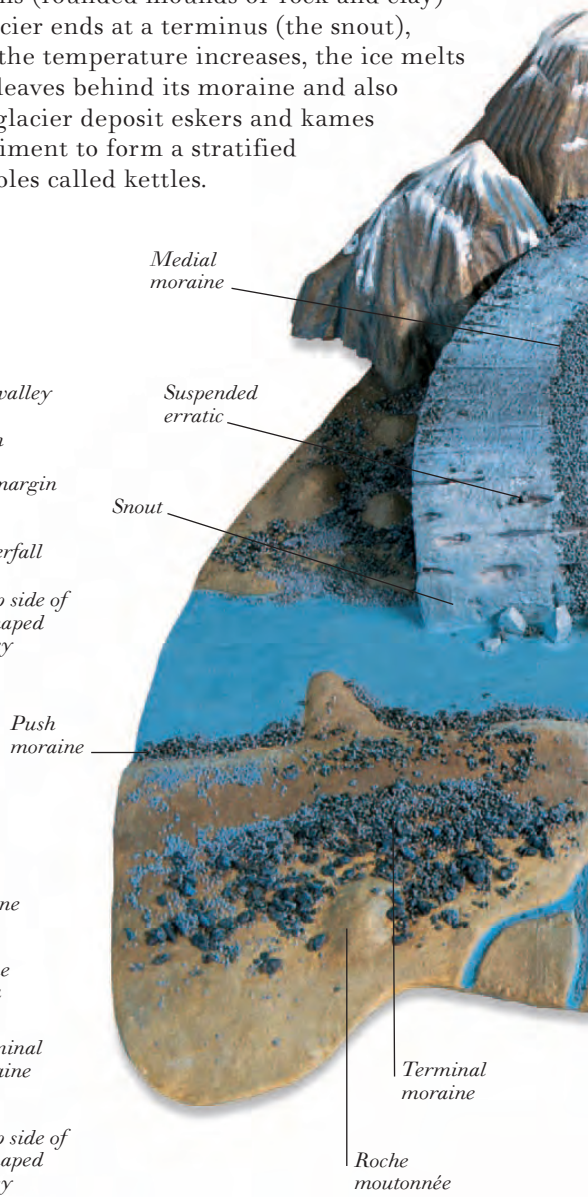
Glaciers

GLACIER BAY, ALASKA

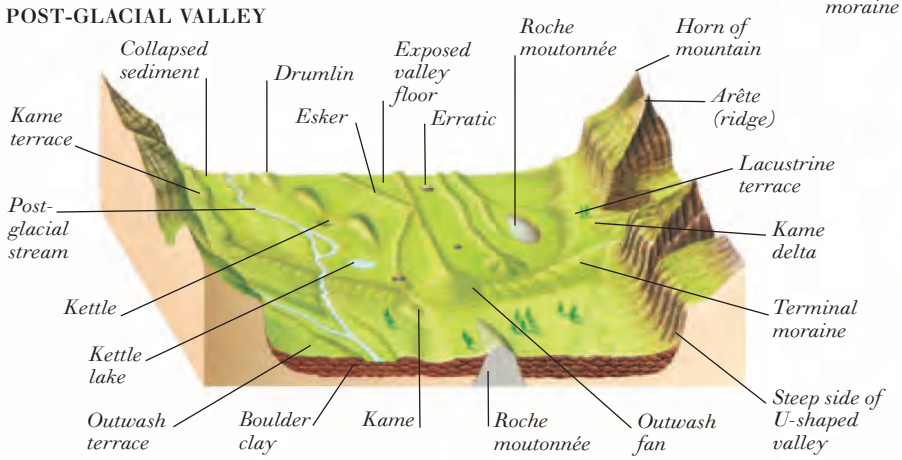
A VALLEY GLACIER IS A LARGE MASS OF ICE that forms on land and moves slowly downhill under its own weight. It is formed from snow that collects in cirques (mountain hollows also known as corries) and compresses into ice as more and more snow accumulates. The cirque is deepened by frost wedging and abrasion (see pp. 282-283), and arêtes (sharp ridges) develop between adjacent cirques. Eventually, so much ice builds up that the glacier begins to move downhill. As the glacier moves it collects moraine (debris), which may range in size from particles of dust to large boulders. The rocks at the base of the glacier erode the glacial valley, giving it a U-shaped cross-section. Under the glacier, *roches moutonnées* (eroded outcrops of hard rock) and drumlins (rounded mounds of rock and clay) are left behind on the valley floor. The glacier ends at a terminus (the snout), where the ice melts as fast as it arrives. If the temperature increases, the ice melts faster than it arrives, and the glacier retreats. The retreating glacier leaves behind its moraine and also erratics (isolated single boulders). Glacial streams from the melting glacier deposit eskers and kames (ridges and mounds of sand and gravel), but carry away the finer sediment to form a stratified outwash plain. Lumps of ice carried on to this plain melt, creating holes called kettles.

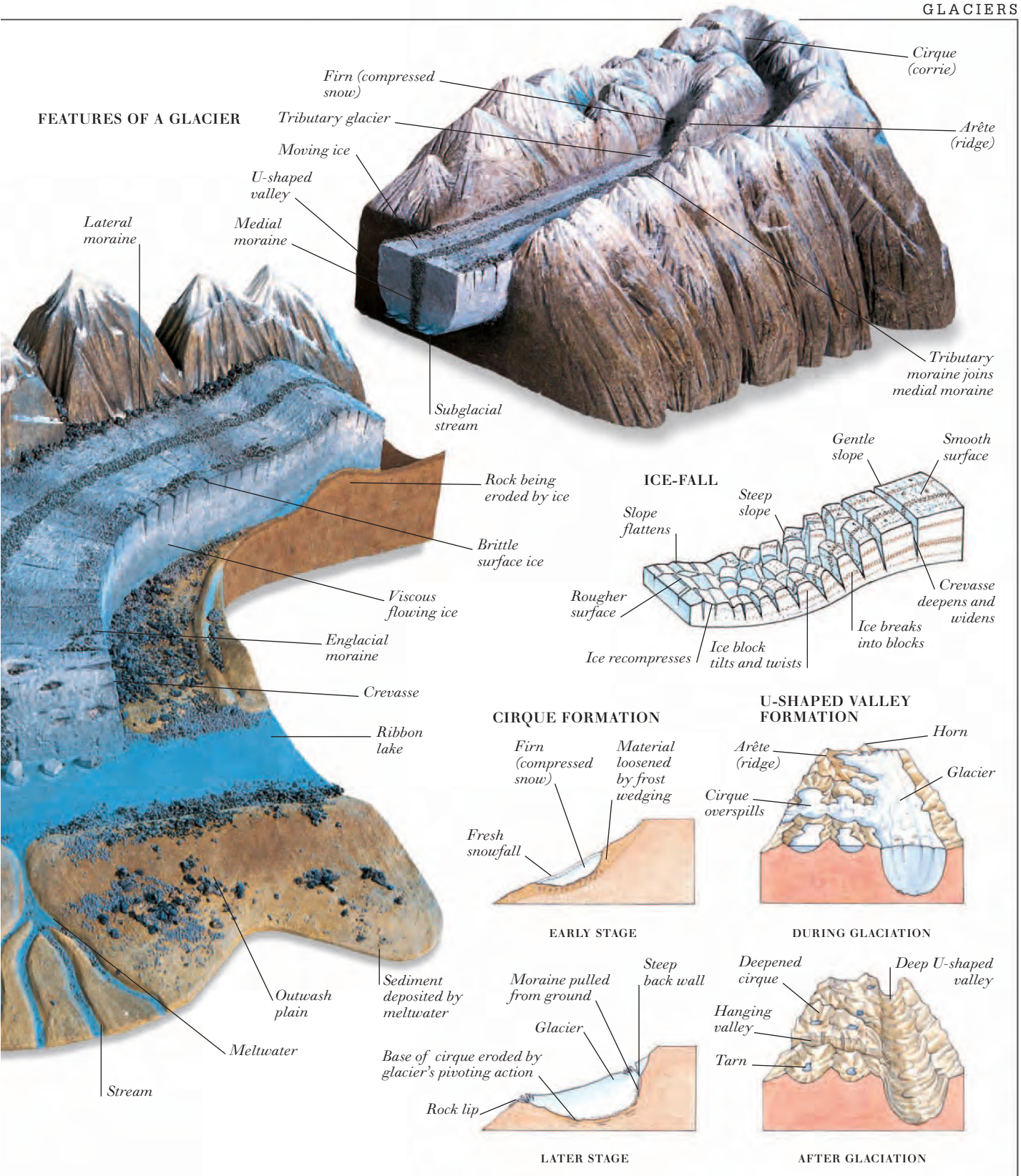
VALLEY GLACIER





POST-GLACIAL VALLEY

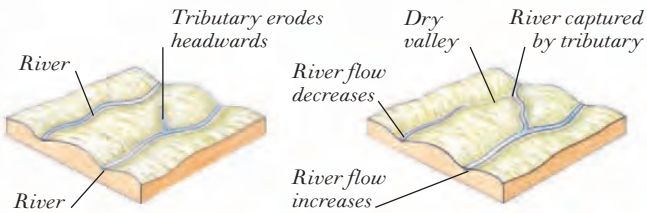



FEATURES OF A GLACIER
Cirque (corrie)
Firn (compressed snow)
Arête (ridge)
Tributary glacier
Moving ice
U-shaped valley
Lateral moraine
Medial moraine
Tributary moraine joins medial moraine
Subglacial stream
Rock being eroded by ice
Brittle surface ice
Viscous flowing ice
Englacial moraine
Crevasse
Ribbon lake
Outwash plain
Sediment deposited by meltwater
Meltwater
Stream
ICE-FALL
Gentle slope
Smooth surface
Steep slope
Slope flattens
Crevasse deepens and widens
Rougher surface
Ice breaks into blocks
Ice recompresses
Ice block tilts and twists
CIRQUE FORMATION
Firn (compressed snow)
Material loosened by frost wedging
Fresh snowfall
EARLY STAGE
Steep back wall
Moraine pulled from ground
Glacier
Base of cirque eroded by glacier's pivoting action
Rock lip
LATER STAGE
U-SHAPED VALLEY FORMATION
Horn
Arête (ridge)
Glacier
Cirque overspills
DURING GLACIATION
Deepened cirque
Deep U-shaped valley
Hanging valley
Tarn
AFTER GLACIATION

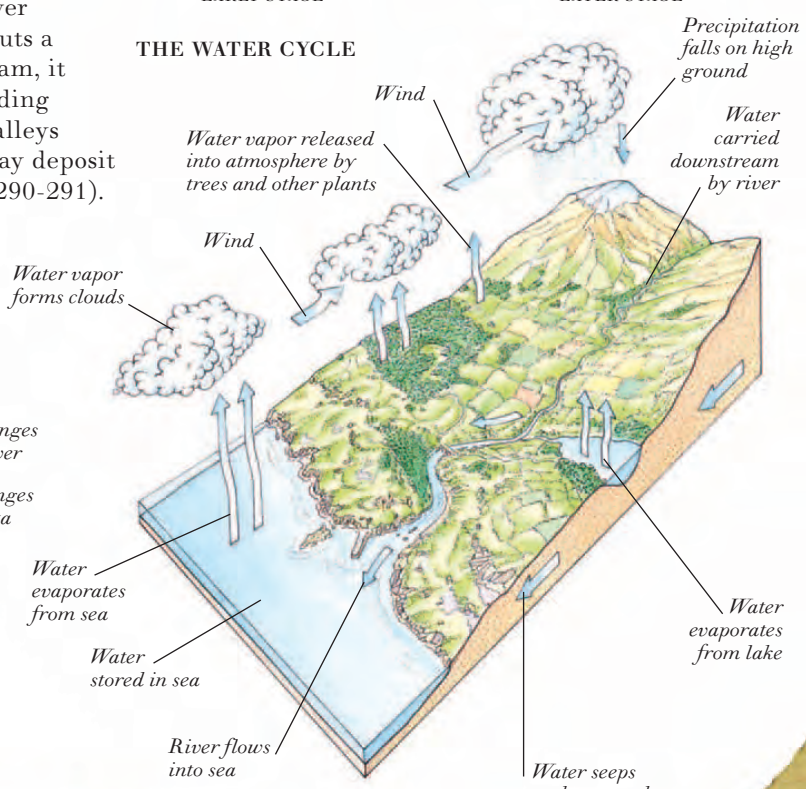
Rivers

RIVERS FORM PART of the water cycle—the continuous circulation of water between the land, sea, and atmosphere. The source of a river may be a mountain spring or lake, or a melting glacier. The course that the river subsequently takes depends on the slope of the terrain and on the rock types and formations over which it flows. In its early, upland stages, a river tumbles steeply over rocks and boulders and cuts a steep-sided V-shaped valley. Farther downstream, it flows smoothly over sediments and forms winding meanders, eroding sideways to create broad valleys and plains. On reaching the coast, the river may deposit sediment to form an estuary or delta (see pp. 290-291).

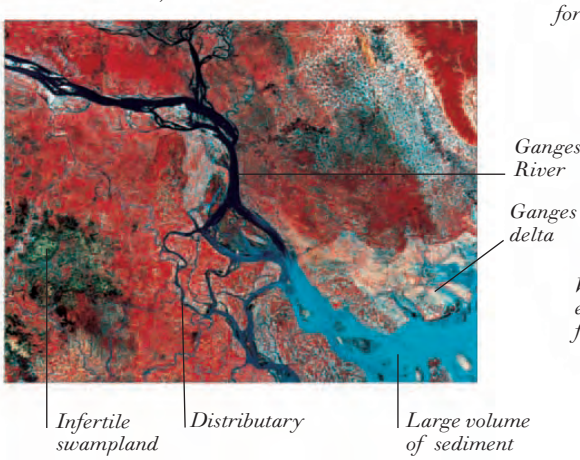
RIVER CAPTURE



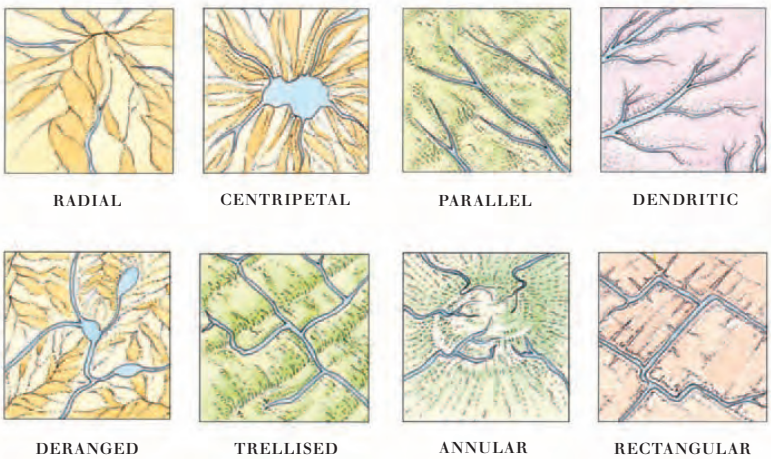
THE WATER CYCLE

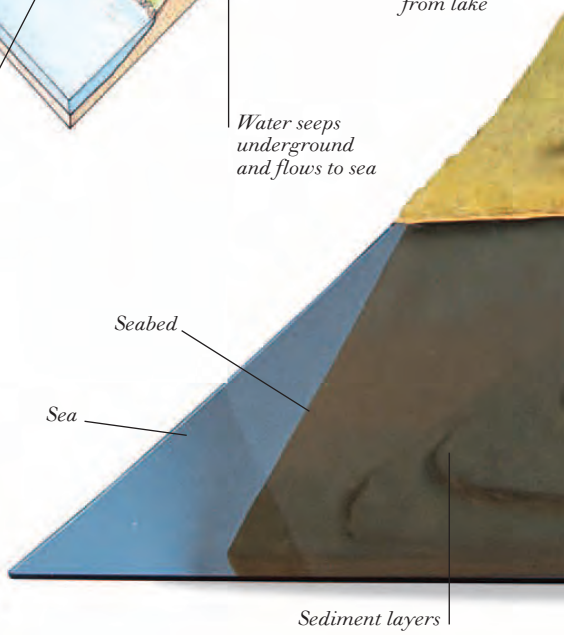


SATELLITE IMAGE OF GANGES RIVER DELTA, BANGLADESH

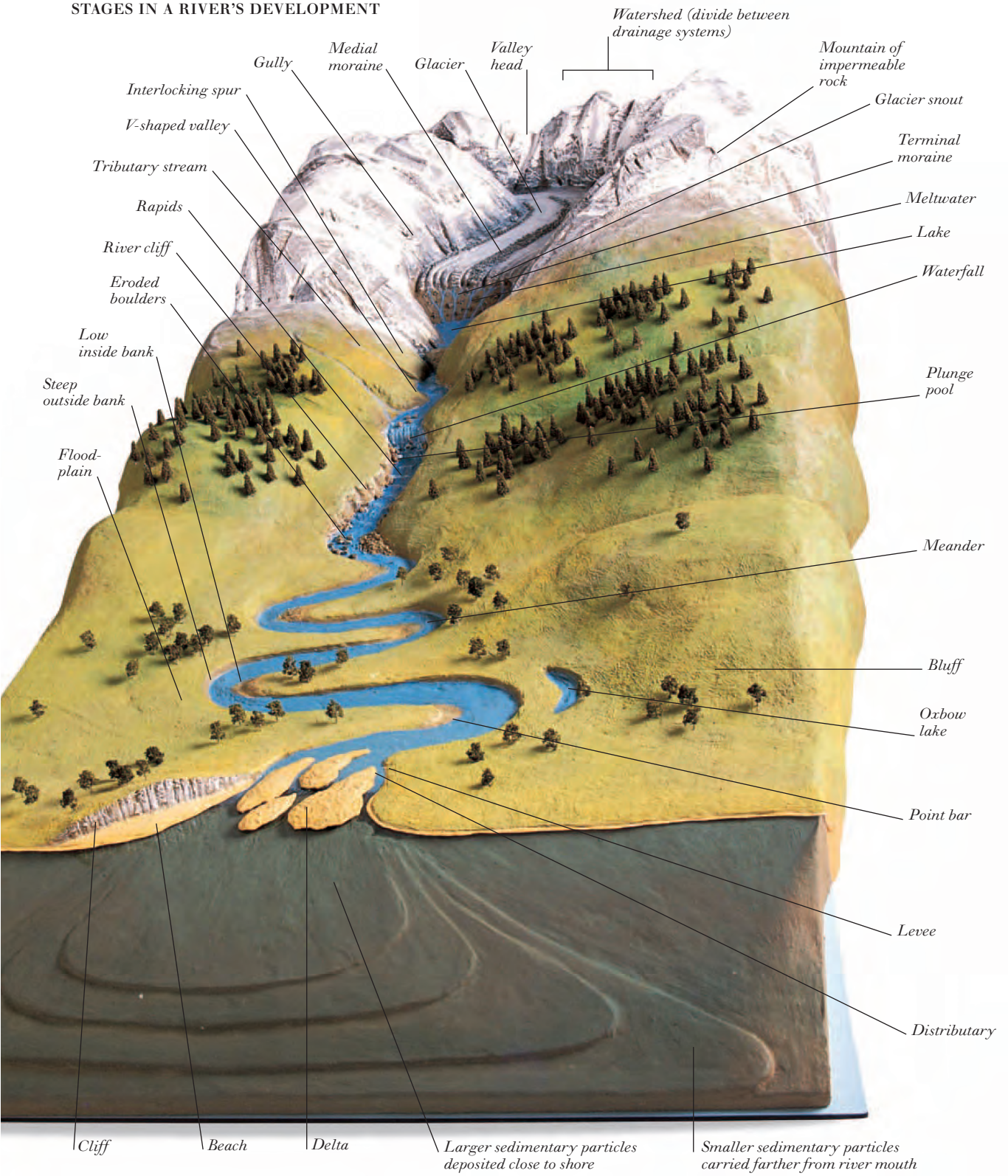


RIVER DRAINAGE PATTERNS





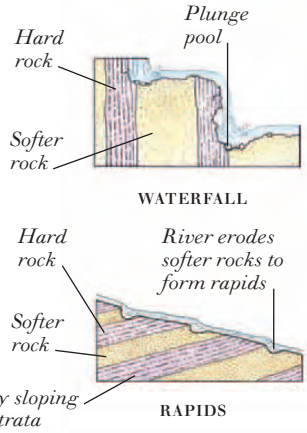
STAGES IN A RIVER'S DEVELOPMENT



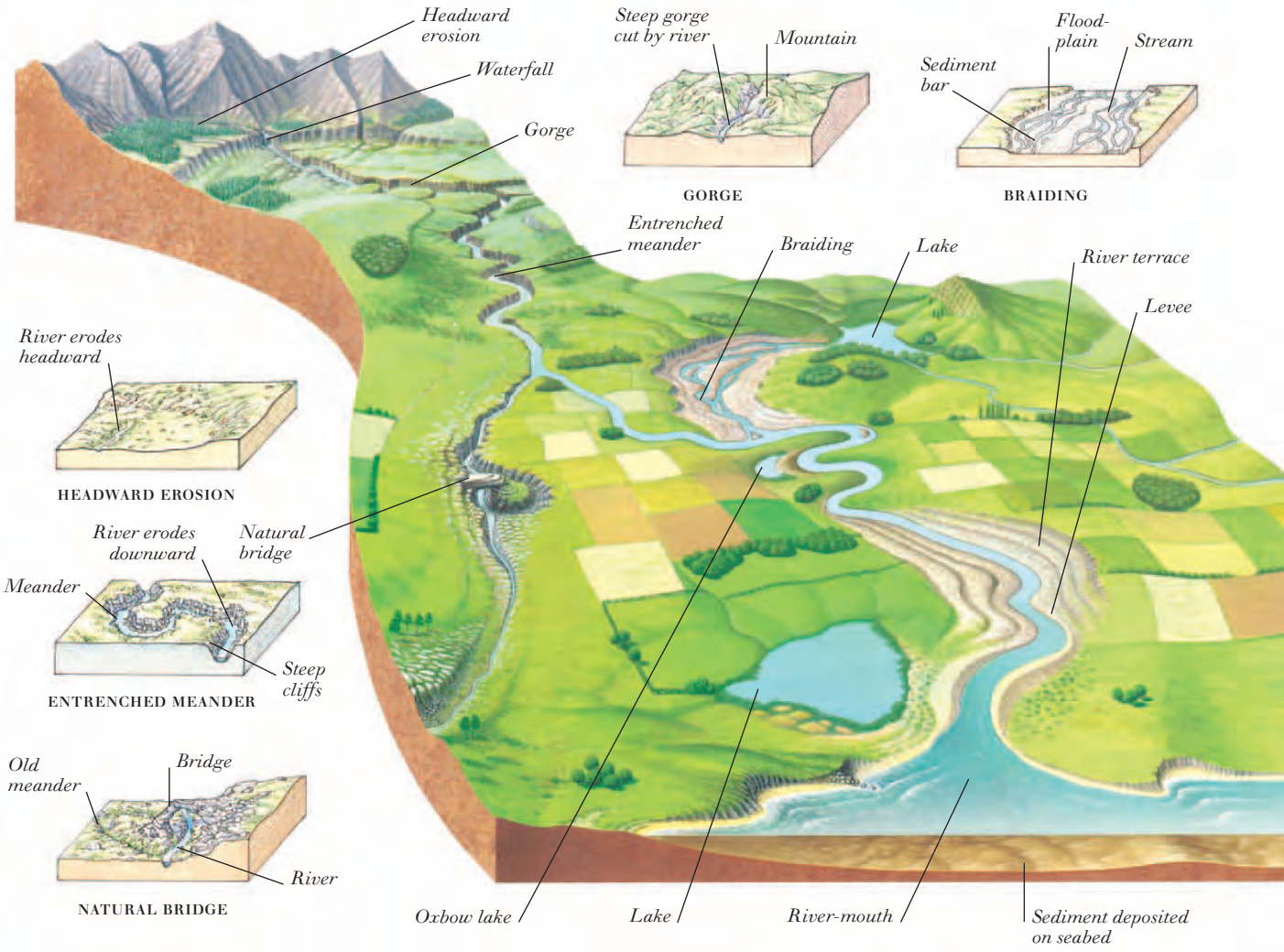
River features

RIVERS ARE ONE OF THE MAJOR FORCES that shape the landscape. Near its source, a river is steep (see pp. 288-289). It erodes downward, carving out V-shaped valleys and deep gorges. Waterfalls and rapids are formed where the river flows from hard rock to softer, more easily eroded rock. Farther downstream, meanders may form and there is greater sideways erosion, resulting in a broad river valley. The river sometimes erodes through the neck of a meander to form an oxbow lake. Sediment deposited on the valley floor by meandering rivers and during floods helps to create a floodplain. Floods may also deposit sediment on the banks of the river to form levees. As a river spills into the sea or a lake, it deposits large amounts of sediment, and may form a delta. A delta is an area of sand bars, swamps, and lagoons through which the river flows in several channels called distributaries—the Mississippi delta, for example. Often, a rise in sea level may have flooded the river mouth to form a broad estuary, a tidal section where seawater mixes with fresh water.

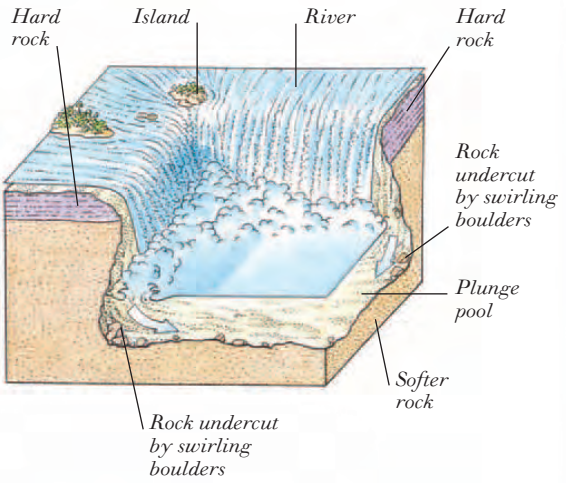
HOW WATERFALLS AND RAPIDS ARE FORMED

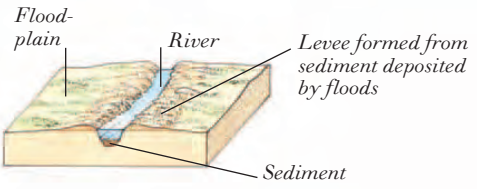


A RIVER VALLEY DRAINAGE SYSTEM

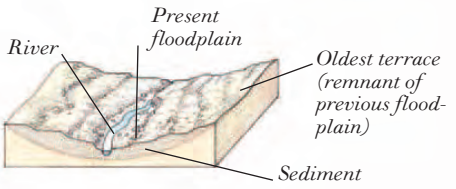


WATERFALL FEATURES



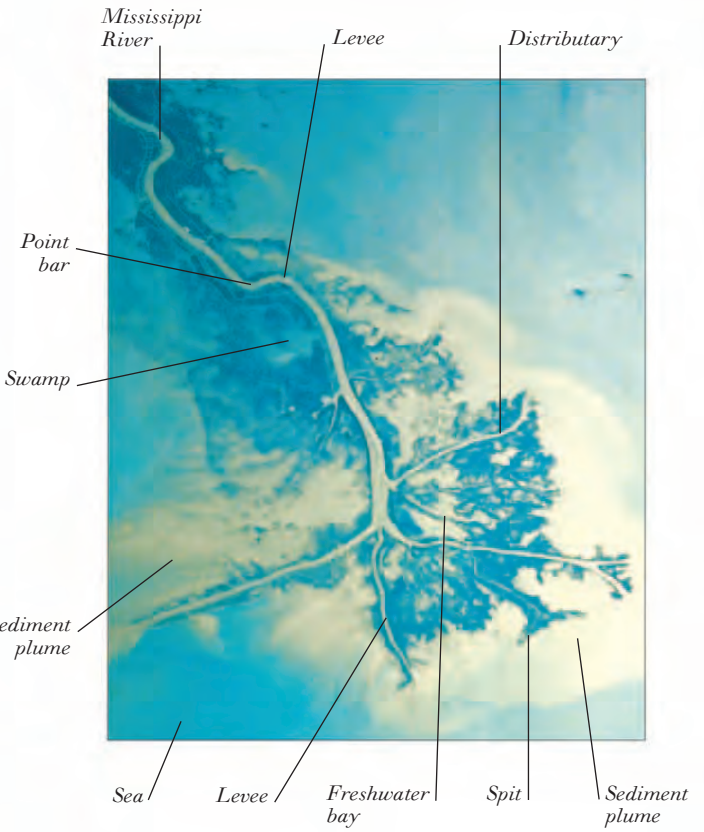


LEVEE

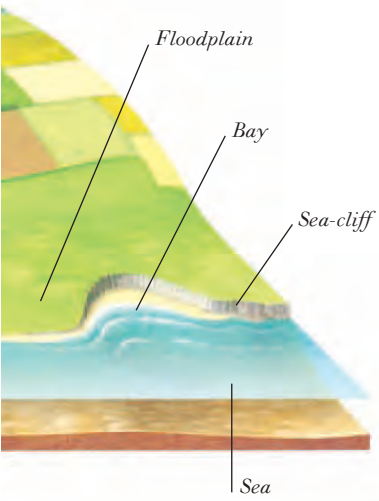


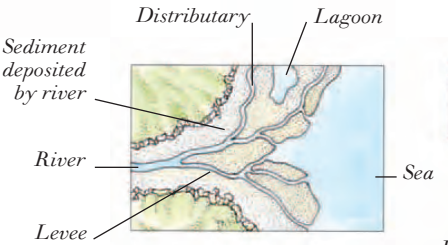
RIVER TERRACE

THE MISSISSIPPI DELTA

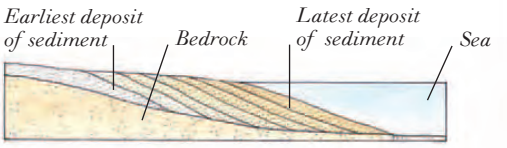


FORMATION OF A DELTA

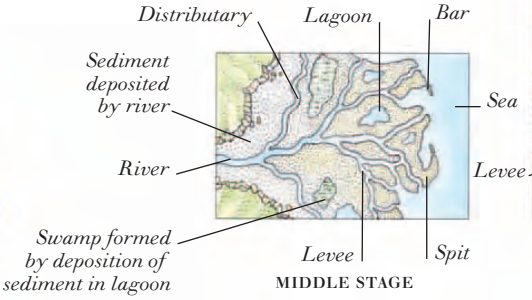




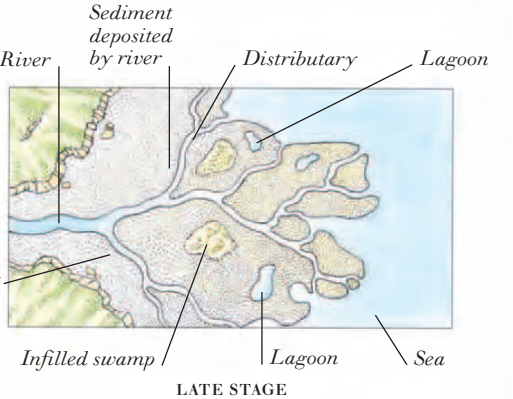
EARLY STAGE



SECTION THROUGH DELTA



MIDDLE STAGE



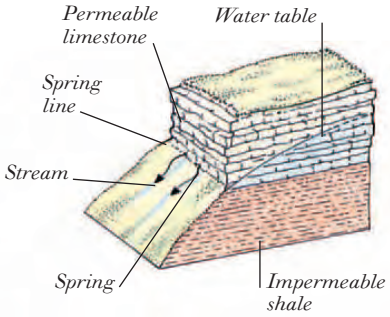
LATE STAGE

Lakes and groundwater

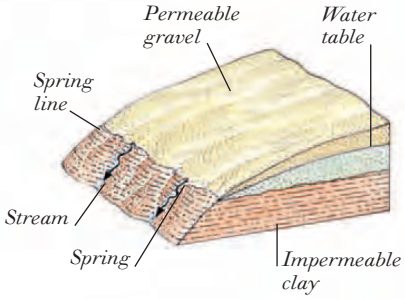
NATURAL LAKE OCCUR WHERE a large quantity of water collects in a hollow in impermeable rock, or is prevented from draining away by a barrier, such as moraine (glacial deposits) or solidified lava. Lakes are often relatively short-lived landscape features, as they tend to become silted up by sediment from the streams and rivers that feed them. Some of the more long-lasting lakes are found in deep rift valleys formed by vertical movements of the Earth's crust (see pp. 58-59)—for example, Lake Baikal in Russia, the world's largest freshwater lake, and the Dead Sea in the Middle East, one of the world's saltiest lakes. Where water is able to drain away, it sinks into the ground until it reaches a layer of impermeable rock, then accumulates in the permeable rock above it; this water-saturated permeable rock is called an aquifer. The saturated zone varies in depth according to seasonal and climatic changes. In wet conditions, the water stored underground builds up, while in dry periods it becomes depleted. Where the upper edge of the saturated zone—the water table—meets the ground surface, water emerges as springs. In an artesian basin, where the aquifer is below an aquiclude (layer of impermeable rock), the water table throughout the basin is determined by its height at the rim. In the center of such a basin, the water table is above ground level. The water in the basin is thus trapped below the water table and can rise under its own pressure along faultlines or well shafts.

LAKE BAIKAL, RUSSIA

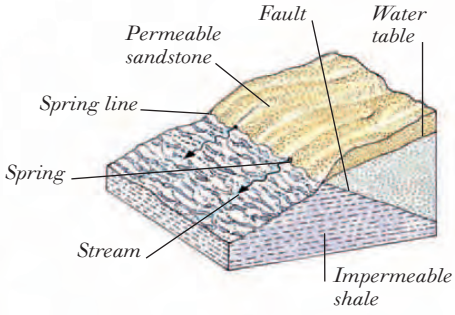
EXAMPLES OF SPRINGS



LIMESTONE SPRING

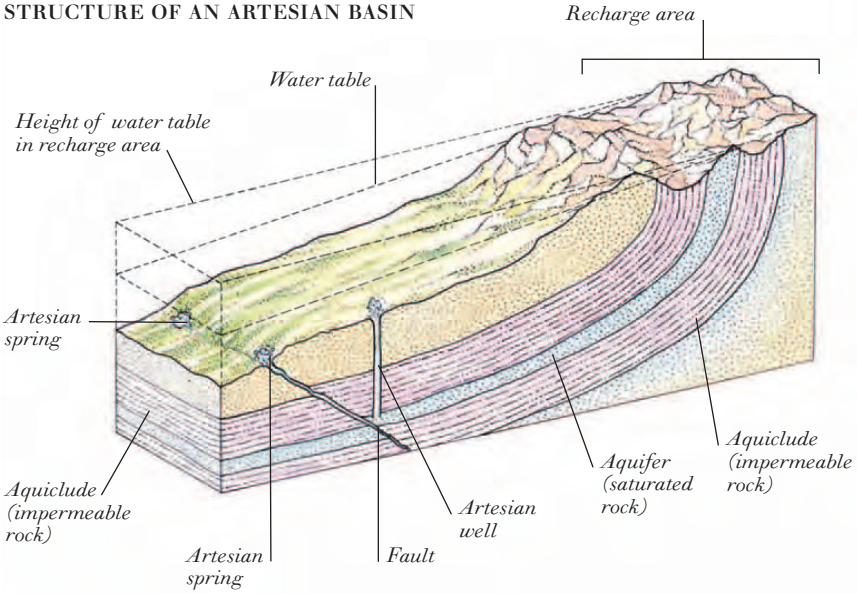


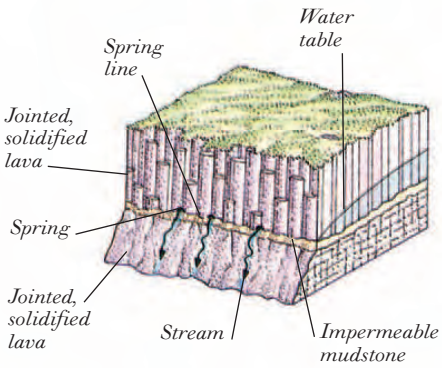
COASTAL (VALLEY) SPRING



FAULT SPRING

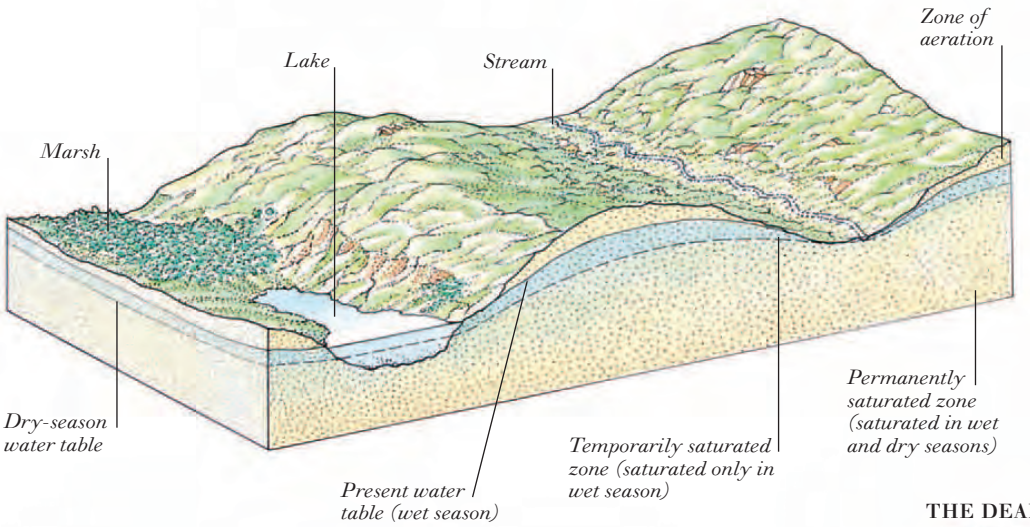
STRUCTURE OF AN ARTESIAN BASIN

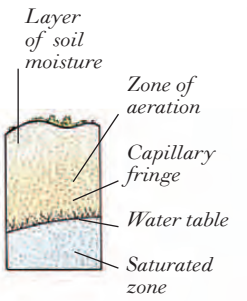




LAVA SPRING

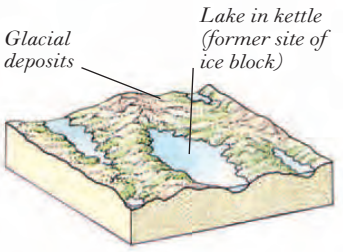
FEATURES OF A GROUNDWATER SYSTEM



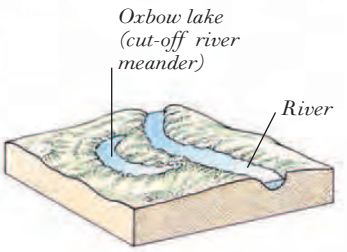


CLOSE-UP OF SURFACE LAYER

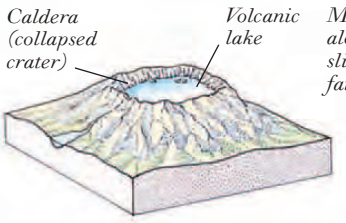
EXAMPLES OF LAKES



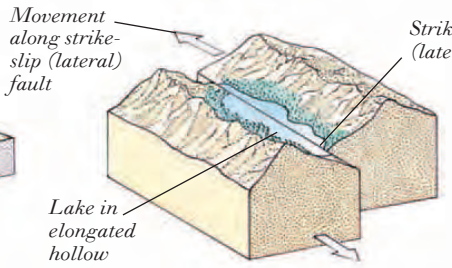
KETTLE LAKE



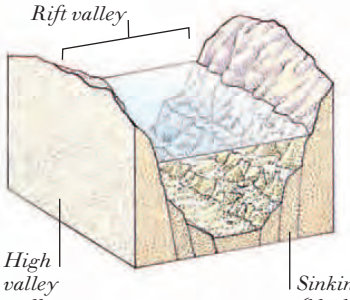
OXBOW LAKE



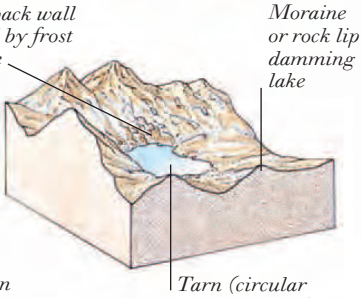
VOLCANIC LAKE



STRIKE-SLIP (LATERAL) FAULT LAKE



GRABEN (BLOCK-FAULT) LAKE



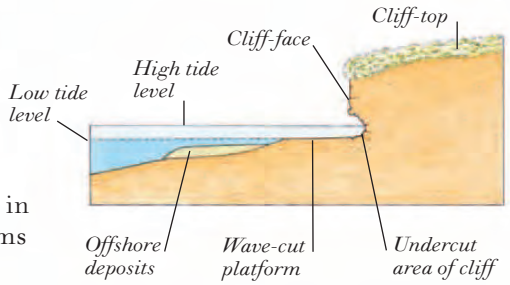
TARN

THE DEAD SEA, ISRAEL/JORDAN

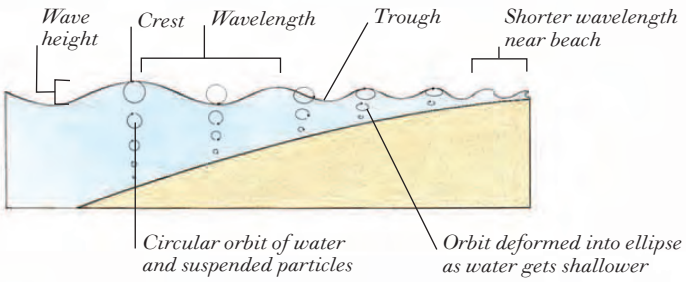
Coastlines

COASTLINES ARE AMONG THE MOST RAPIDLY changing landscape features. Some are eroded by waves, wind, and rain, causing cliffs to be undercut and caves to be hollowed out of solid rock. Others are built up by waves transporting sand and small rocks in a process known as longshore drift, and by rivers depositing sediment in deltas. Additional influences include the activities of living organisms such as coral, crustal movements, and sea-level variations due to climatic changes. Rising land or a drop in sea level creates an emergent coastline, with cliffs and beaches stranded above the new shoreline. Sinking land or a rise in sea level produces a drowned coastline, typified by fjords (submerged glacial valleys) or submerged river valleys.

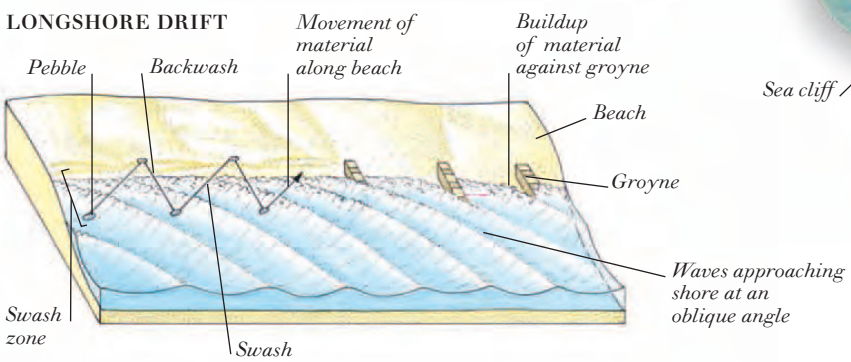
FEATURES OF A SEA CLIFF

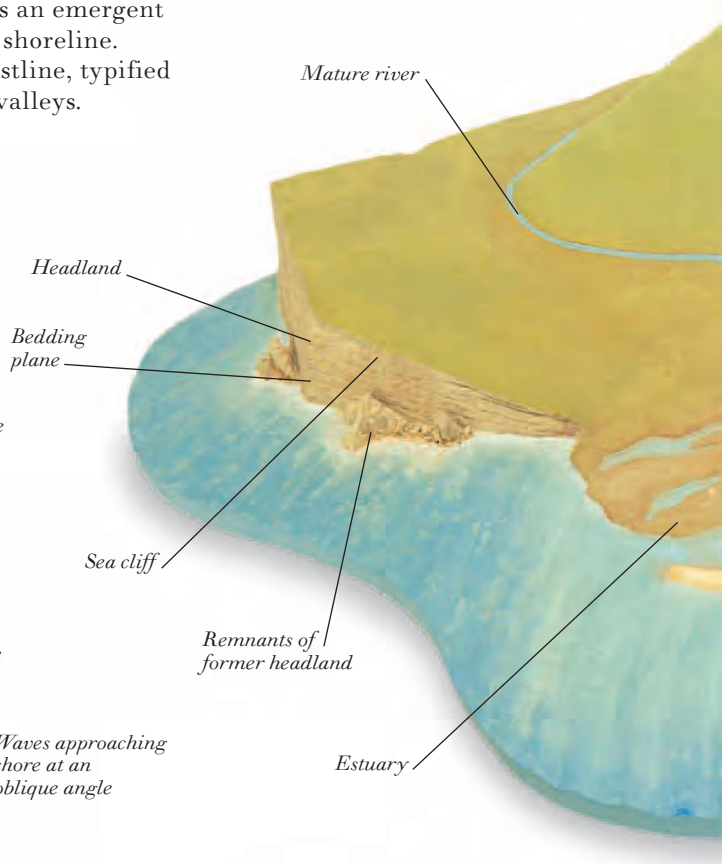


FEATURES OF WAVES

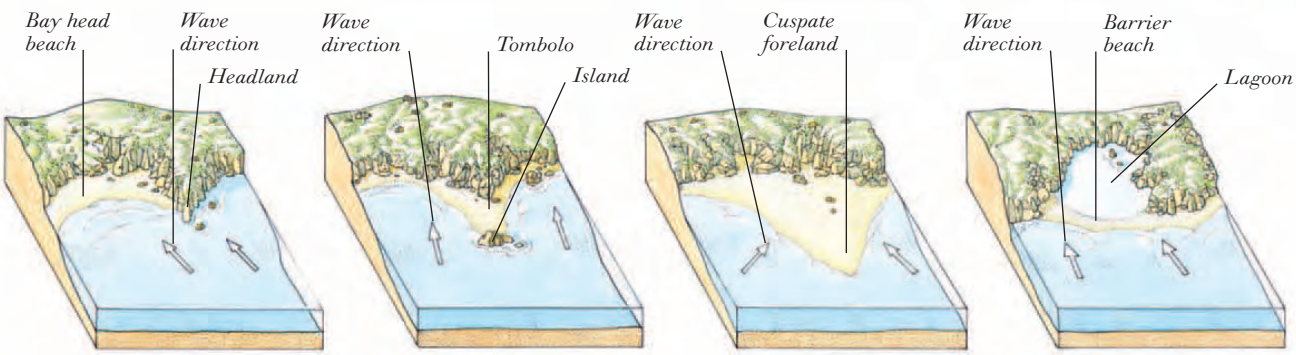


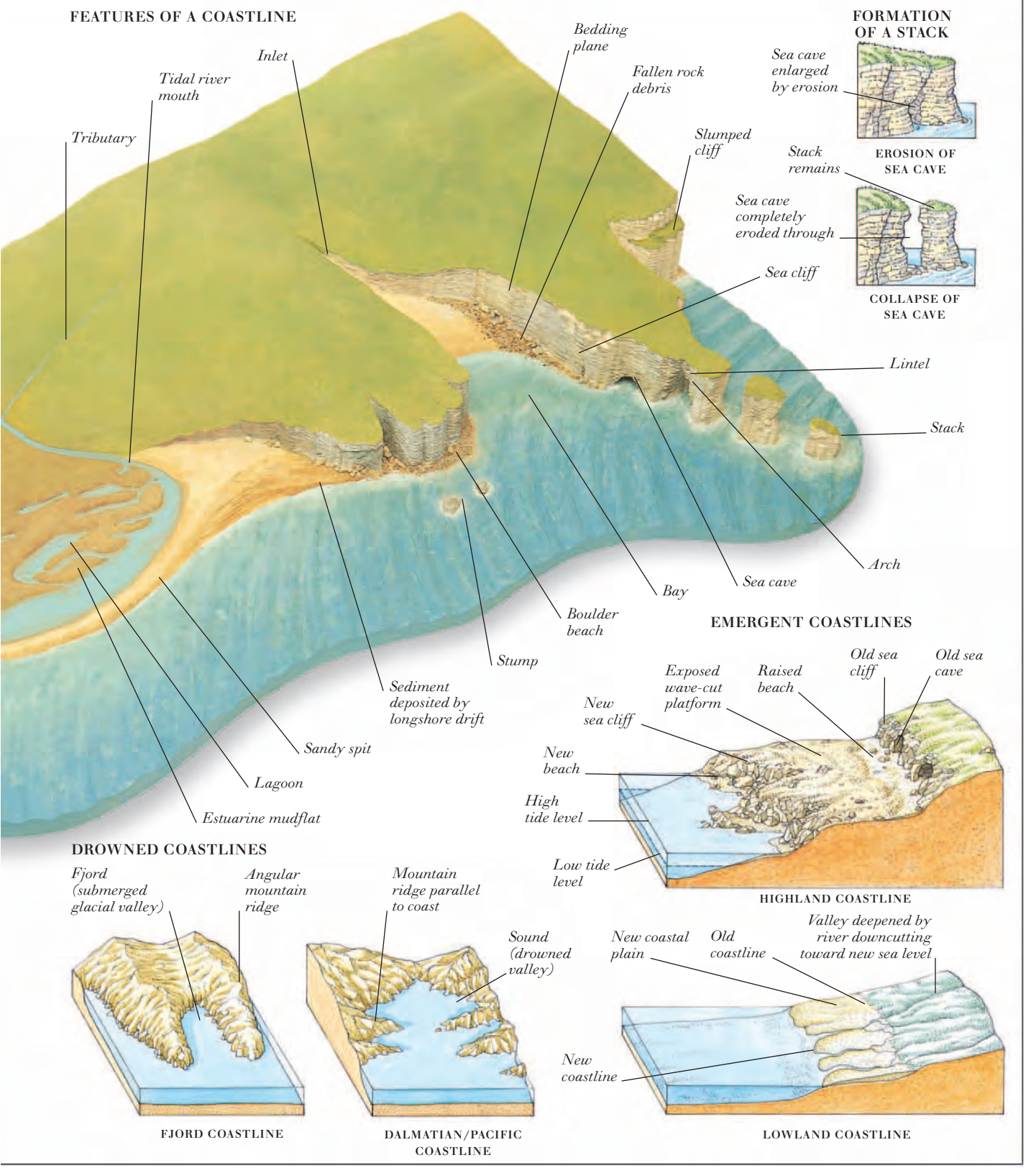
LONGSHORE DRIFT





DEPOSITIONAL FEATURES OF COASTLINES

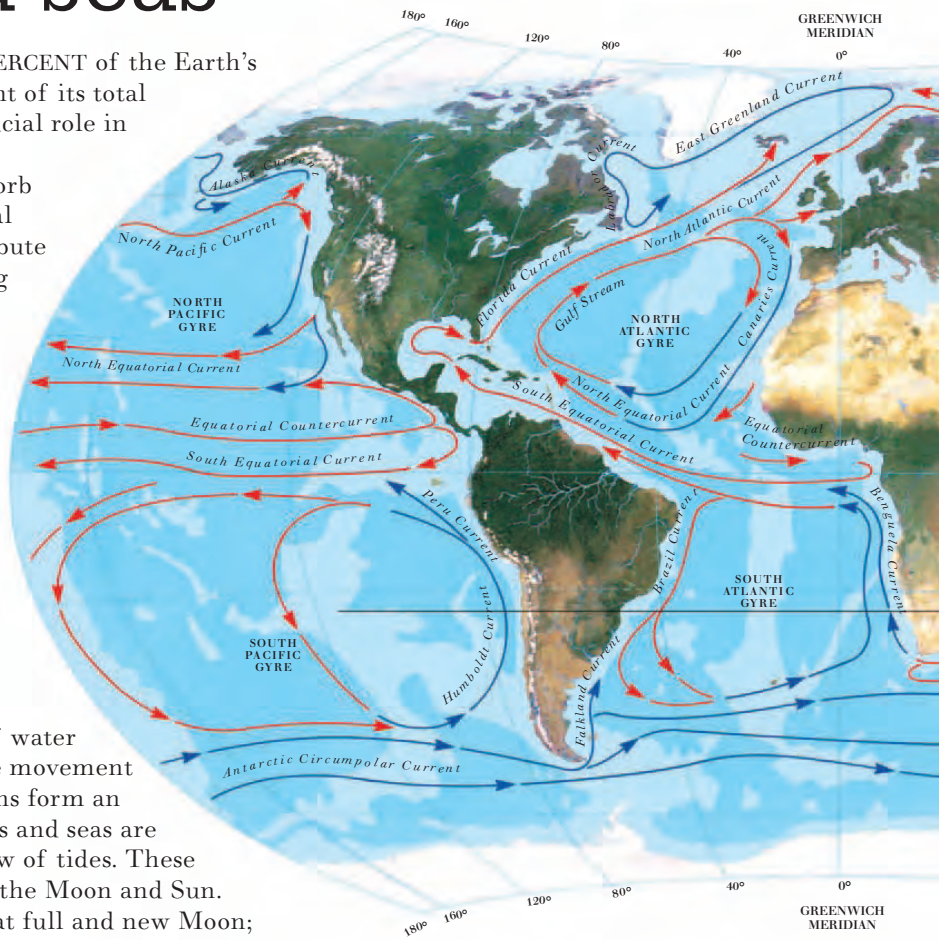



FEATURES OF A COASTLINE
Inlet
Tidal river mouth
Tributary
Bedding plane
Fallen rock debris
Slumped cliff
Sea cliff
Lintel
Stack
Arch
Sea cave
Bay
Boulder beach
Stump
Sediment deposited by longshore drift
Sandy spit
Lagoon
Estuarine mudflat
FORMATION OF A STACK
Sea cave enlarged by erosion
EROSION OF SEA CAVE
Stack remains
Sea cave completely eroded through
COLLAPSE OF SEA CAVE
EMERGENT COASTLINES
Old sea cliff
Old sea cave
Exposed wave-cut platform
Raised beach
New sea cliff
New beach
High tide level
Low tide level
HIGHLAND COASTLINE
DROWNED COASTLINES
Fjord (submerged glacial valley)
Angular mountain ridge
FJORD COASTLINE
Mountain ridge parallel to coast
Sound (drowned valley)
DALMATIAN/PACIFIC COASTLINE
New coastal plain
Old coastline
Valley deepened by river downcutting toward new sea level
New coastline
LOWLAND COASTLINE

Oceans and seas

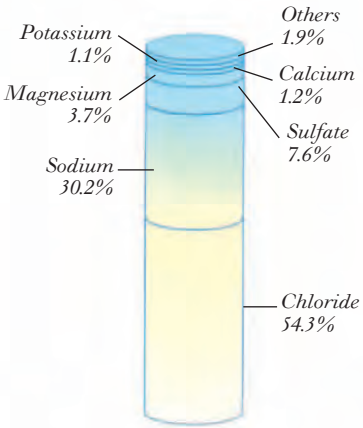
OCEANS AND SEAS COVER ABOUT 70 PERCENT of the Earth's surface and account for about 97 percent of its total water. These oceans and seas play a crucial role in regulating temperature variations and determining climate. Their waters absorb heat from the Sun, especially in tropical regions, and the surface currents distribute it around the Earth, warming overlying air masses and neighboring land in winter and cooling them in summer. The oceans are never still. Differences in temperature and salinity drive deep current systems, while surface currents are generated by winds blowing over the oceans. All currents are deflected—to the right in the Northern Hemisphere, to the left in the Southern Hemisphere—as a result of the Earth's rotation. This deflective factor is known as the Coriolis force. A current that begins on the surface is immediately deflected. This current in turn generates a current in the layer of water beneath, which is also deflected. As the movement is transmitted downward, the deflections form an Ekman spiral. The waters of the oceans and seas are also moved by the constant ebb and flow of tides. These are caused by the gravitational pull of the Moon and Sun. The highest tides (Spring tides) occur at full and new Moon; the lowest tides (neap tides) occur at first and last quarter.

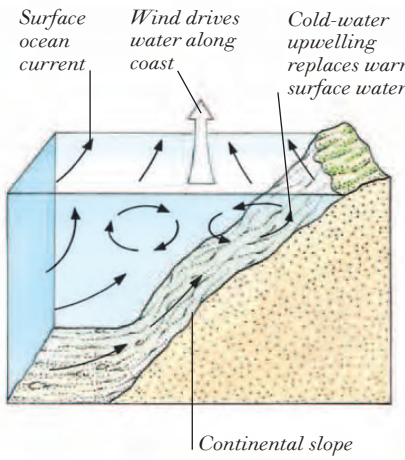
SURFACE CURRENTS



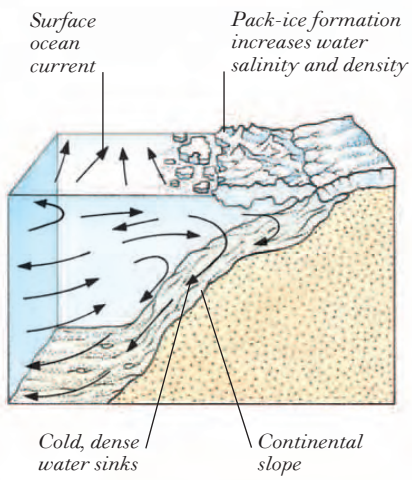
OFFSHORE CURRENTS

SALT CONTENT OF SEAWATER

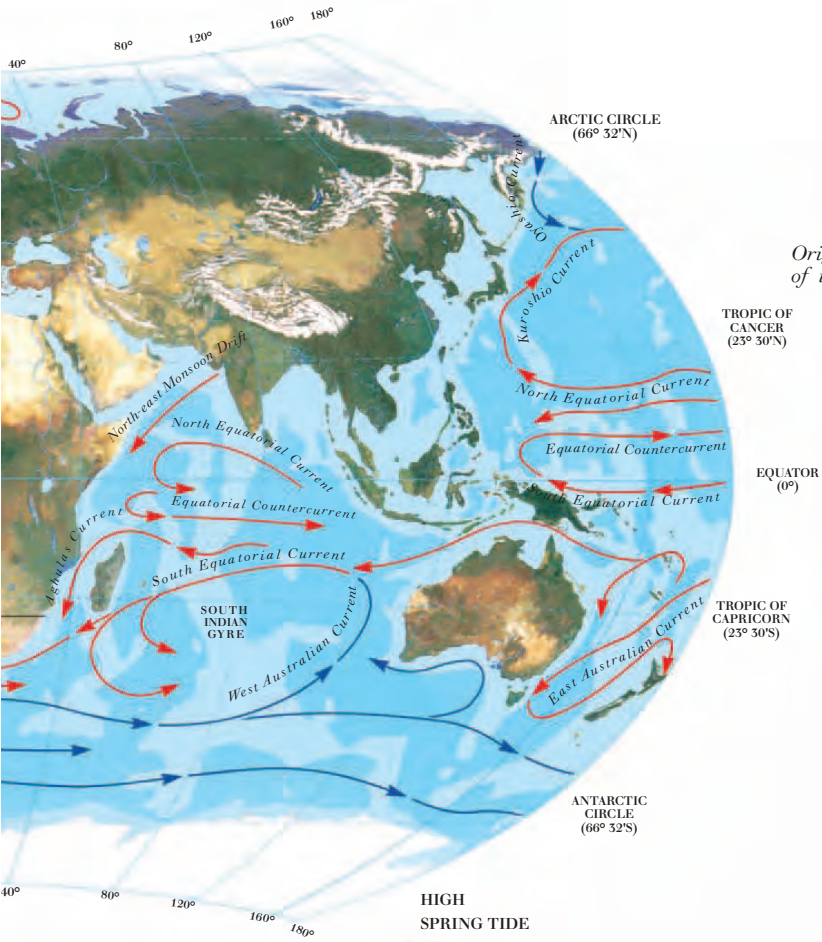




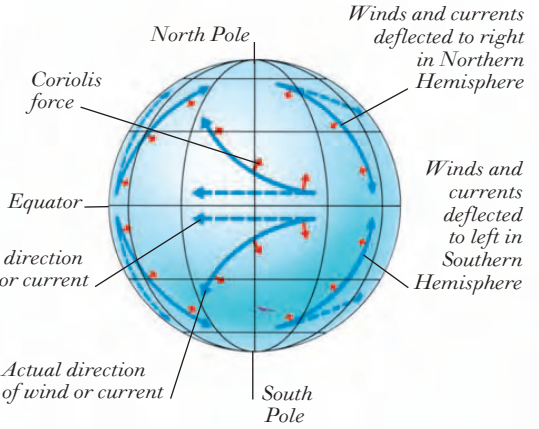
COLD-WATER UPWELLING (SOUTHERN HEMISPHERE)



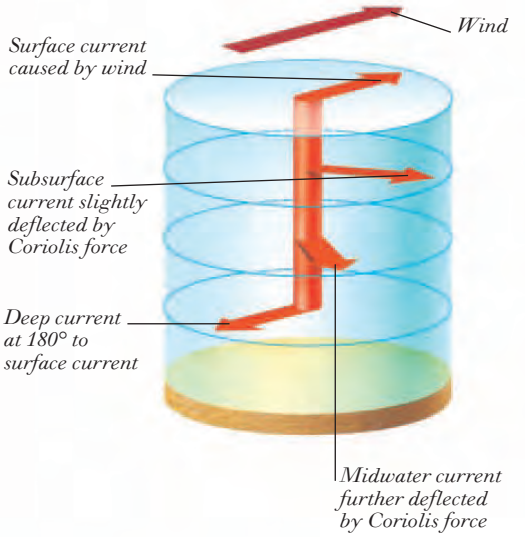
POLAR BOTTOM WATER



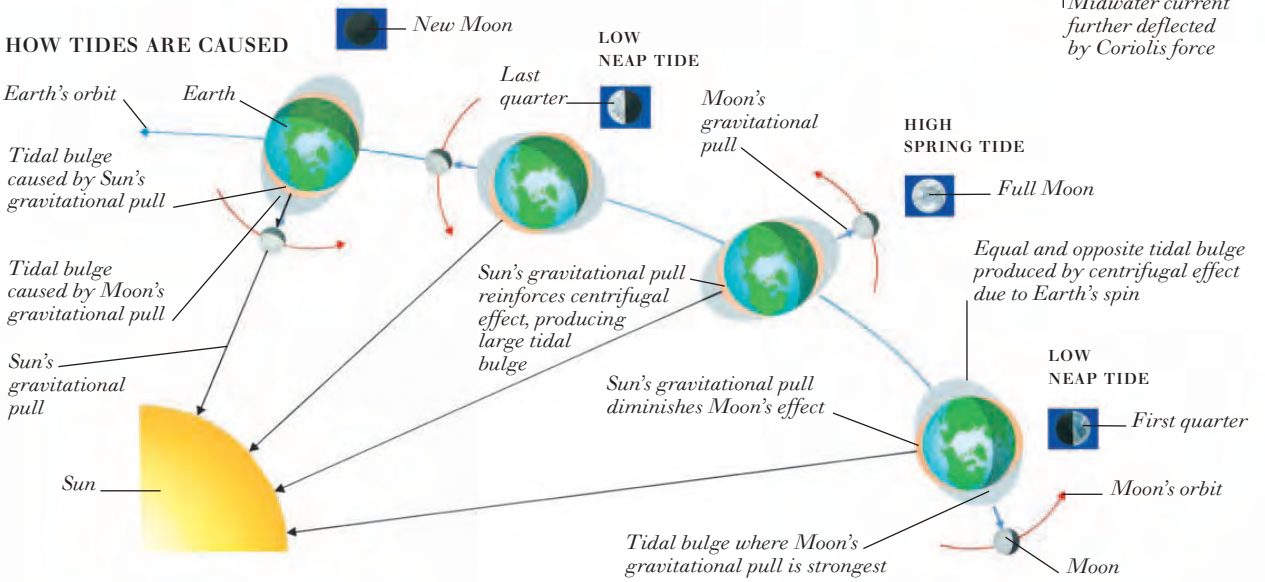
EFFECT OF CORIOLIS FORCE



EKMAN SPIRAL (NORTHERN HEMISPHERE)



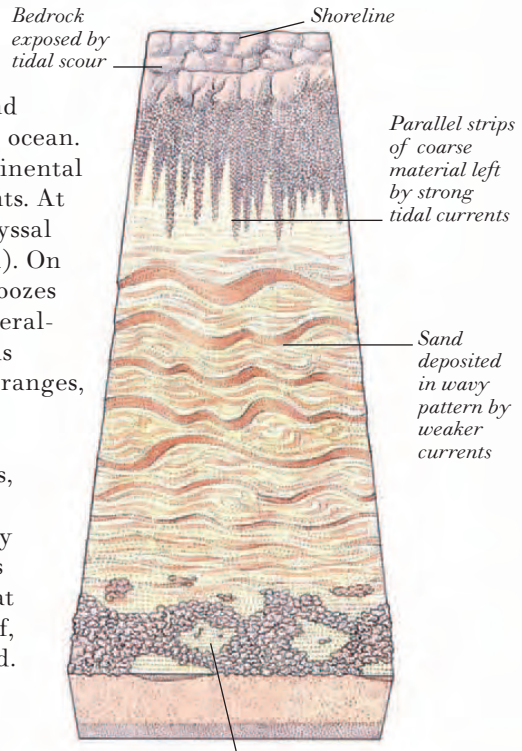
HOW TIDES ARE CAUSED



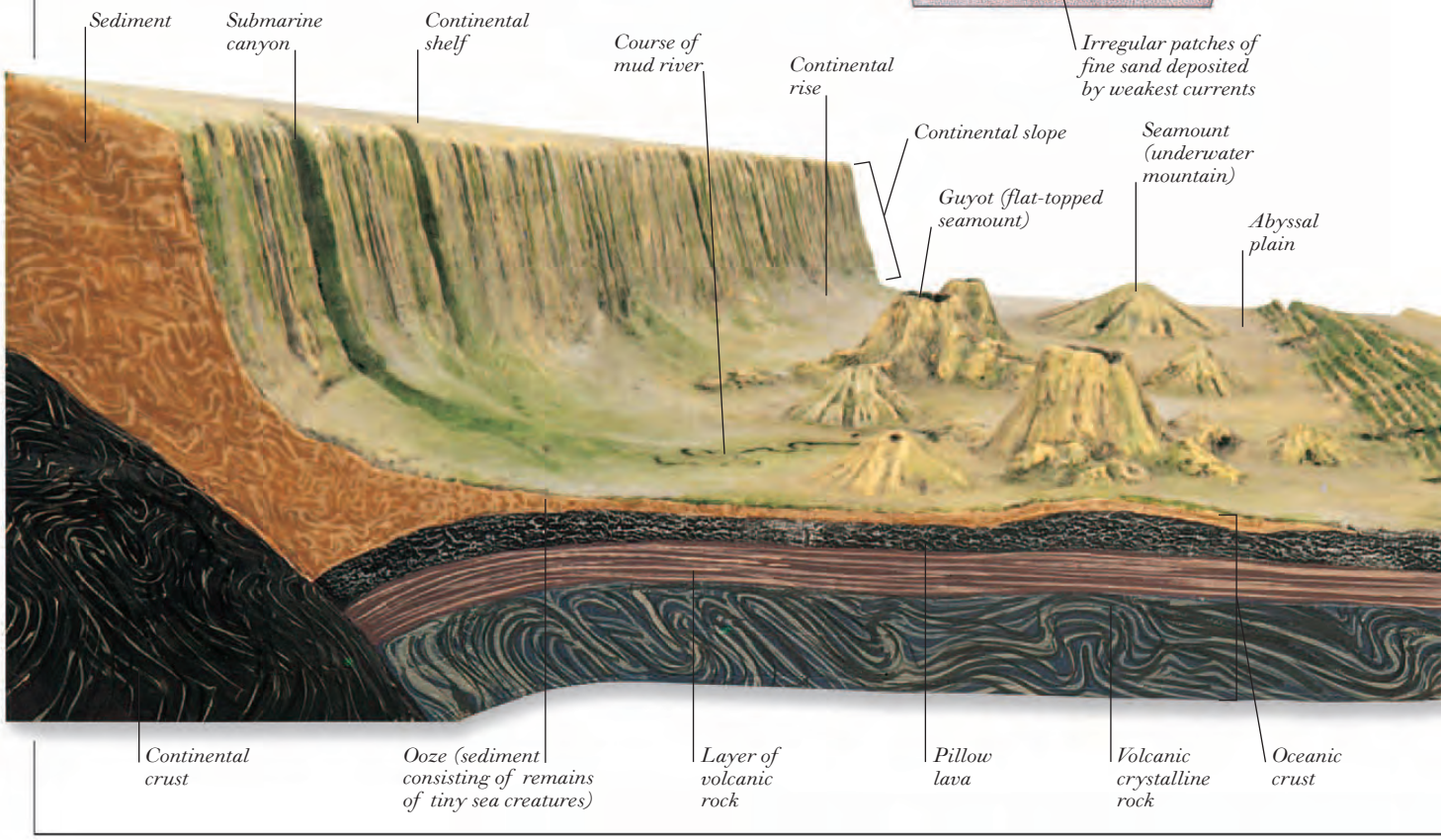
The ocean floor

THE OCEAN FLOOR COMPRISES TWO SECTIONS: the continental shelf and slope, and the deep-ocean floor. The continental shelf and slope are part of the continental crust, but may extend far into the ocean. Sloping quite gently to a depth of about 460 feet (140 m), the continental shelf is covered in sandy deposits shaped by waves and tidal currents. At the edge of the continental shelf, the seabed slopes down to the abyssal plain, which lies at an average depth of about 12,500 feet (3,800 m). On this deep-ocean floor is a layer of sediment made up of clays, fine oozes formed from the remains of tiny sea creatures, and occasional mineral-rich deposits. Echo-sounding and remote sensing from satellites has revealed that the abyssal plain is divided by a system of mountain ranges, far bigger than any on land—the mid-ocean ridge. Here, magma (molten rock) wells up from the Earth's interior and solidifies, widening the ocean floor (see pp. 58-59). As the ocean floor spreads, volcanoes that have formed over hot spots in the crust move away from their magma source; they become extinct and are increasingly submerged and eroded. Volcanoes eroded below sea level remain as seamounts (underwater mountains). In warm waters, a volcano that projects above the ocean surface often acquires a fringing coral reef, which may develop into an atoll as the volcano becomes submerged.

CONTINENTAL-SHELF FLOOR



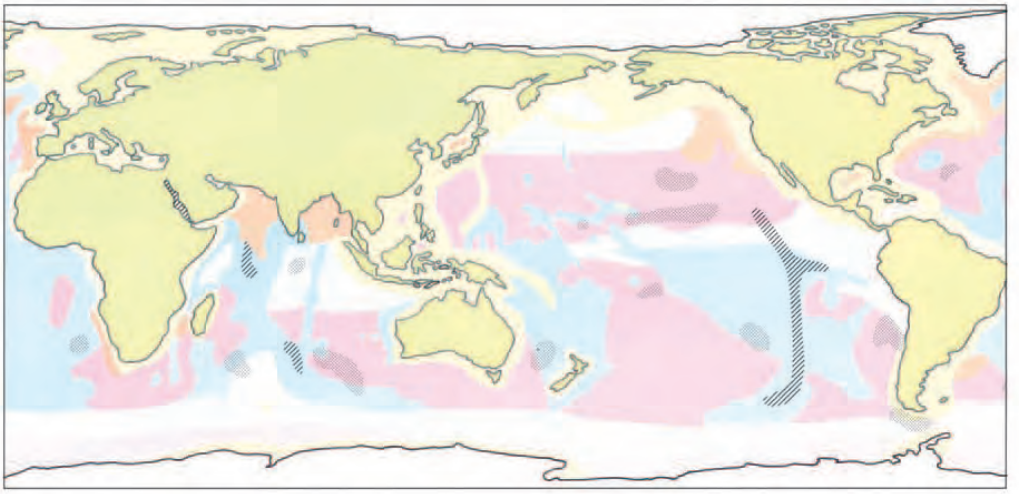
FEATURES OF THE OCEAN FLOOR



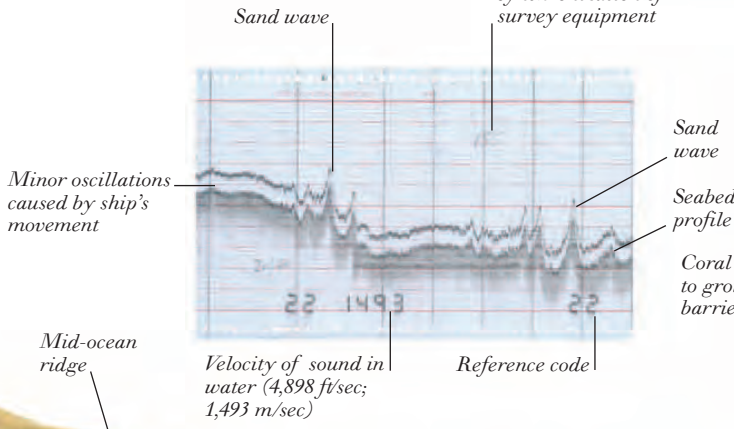
KEY

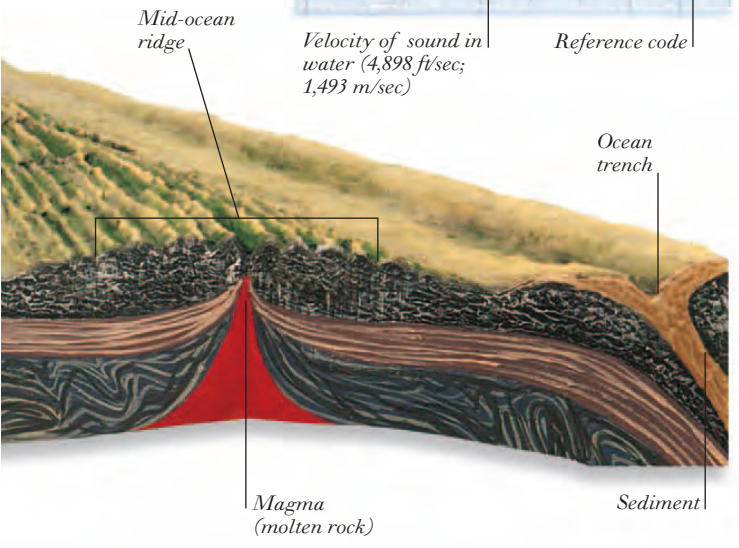
- Calcareous ooze
- Pelagic clay
- Glacial sediments
- Siliceous ooze
- Terrigenous sediments
- Continental margin sediments
- Metalliferous muds
- Major nodule fields

DEEP-OCEAN FLOOR SEDIMENTS

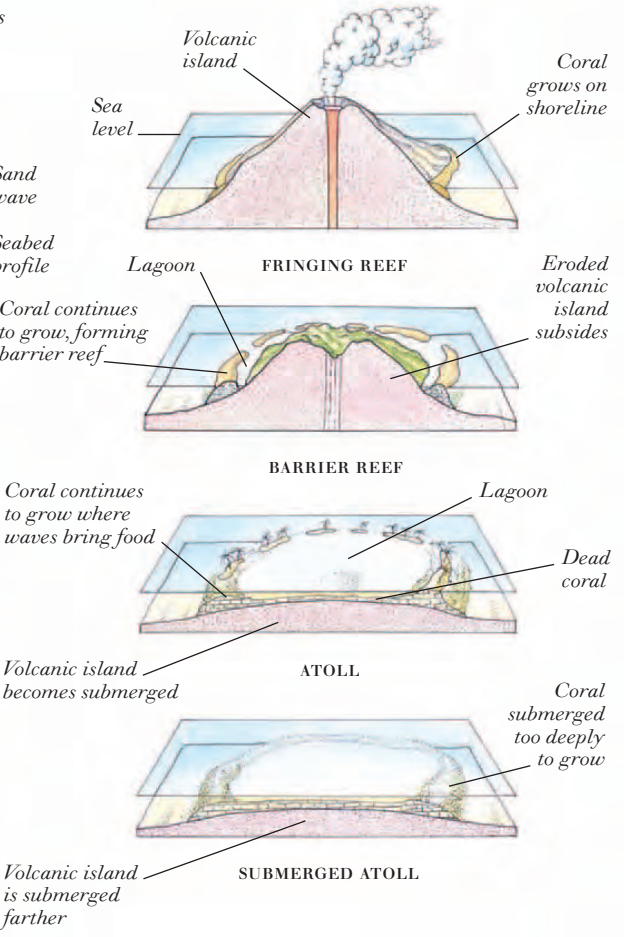


ECHO-SOUND PROFILE OF OCEAN FLOOR





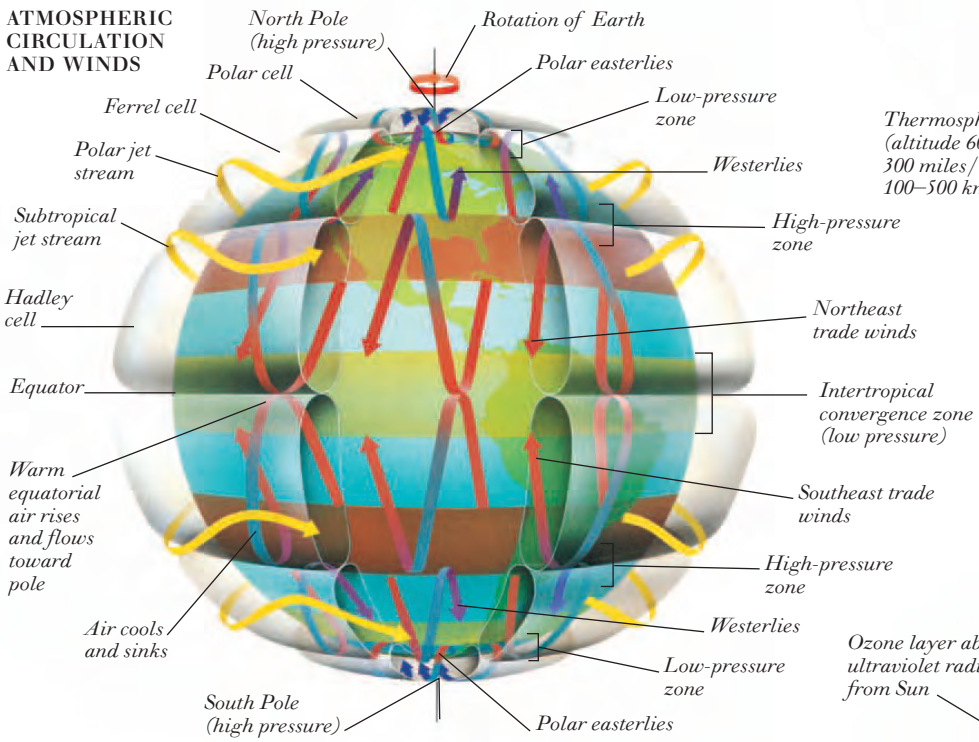
DEVELOPMENT OF AN ATOLL

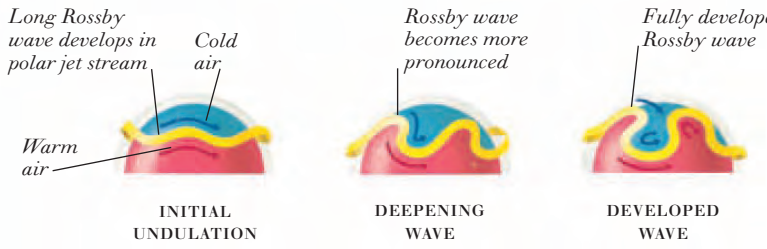


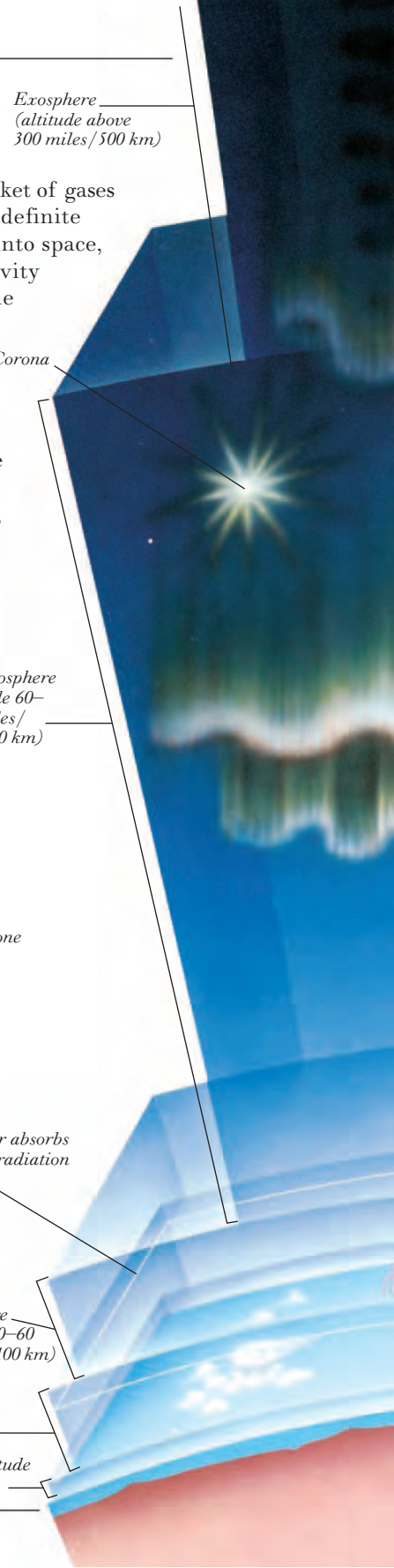
The atmosphere

JET STREAM

THE EARTH IS SURROUNDED BY ITS ATMOSPHERE, a blanket of gases that enables life to exist on the planet. This layer has no definite outer edge, gradually becoming thinner until it merges into space, but over 80 percent of atmospheric gases are held by gravity within about 12 miles (20 km) of the Earth's surface. The atmosphere blocks out much harmful ultraviolet solar radiation, and insulates the Earth against extremes of temperature by limiting both incoming solar radiation and the escape of reradiated heat into space. This natural balance may be distorted by the greenhouse effect, as gases such as carbon dioxide have built up in the atmosphere, trapping more heat. Close to the Earth's surface, differences in air temperature and pressure cause air to circulate between the equator and poles. This circulation, together with the Coriolis force, gives rise to the prevailing surface winds and the high-level jet streams.

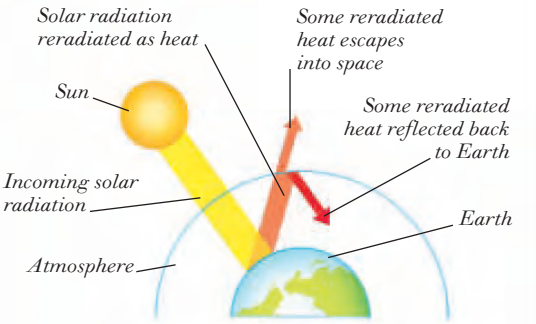




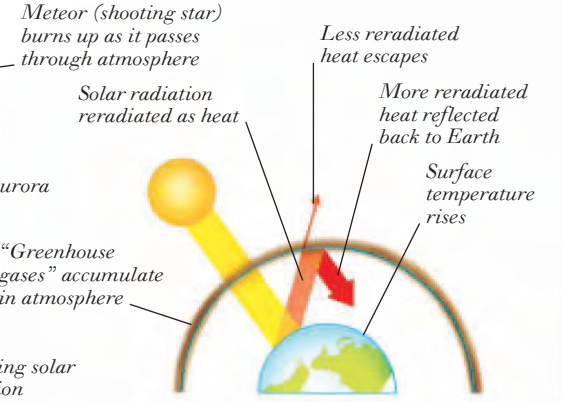


STRUCTURE OF THE ATMOSPHERE

GLOBAL WARMING

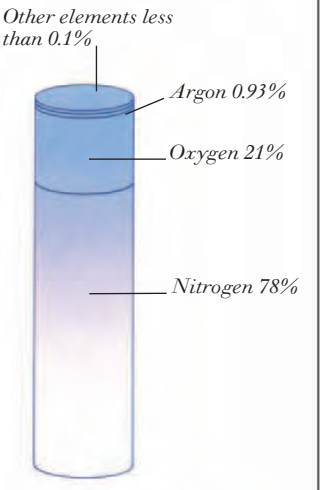


NATURALLY MODERATED GREENHOUSE EFFECT



UNBALANCED GREENHOUSE EFFECT

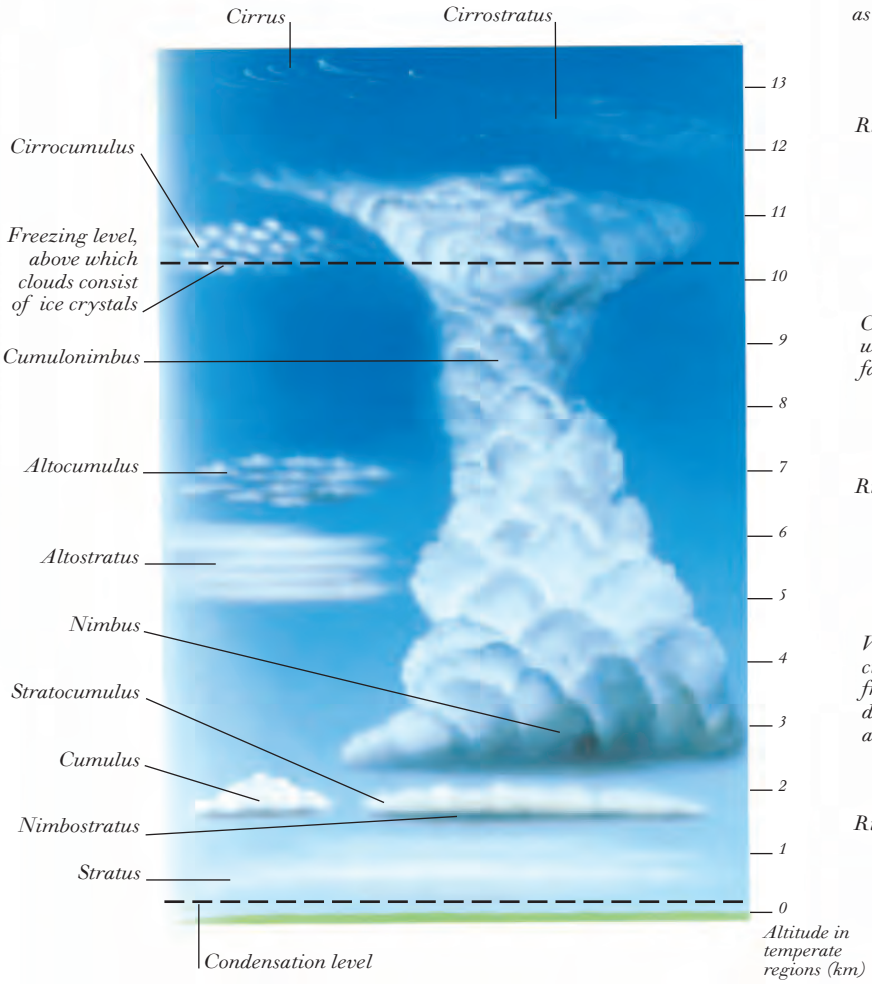
COMPOSITION OF THE LOWER ATMOSPHERE



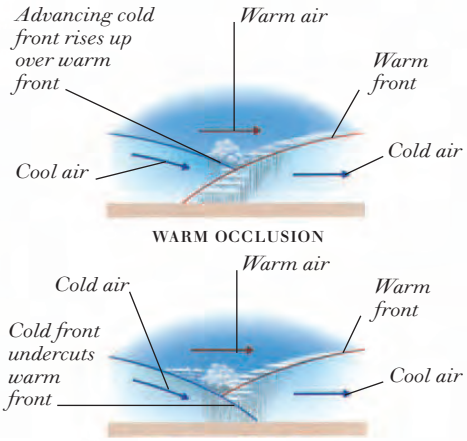
Weather

WEATHER IS DEFINED AS THE ATMOSPHERIC CONDITIONS at a particular time and place; climate is the average weather conditions for a given region over time. Weather is assessed in terms of temperature, wind, cloud cover, and precipitation, such as rain or snow. Good weather is associated with high-pressure areas, where air is sinking. Cloudy, wet, changeable weather is common in low-pressure zones with rising, unstable air. Such conditions occur at temperate latitudes, where warm air meets cool air along the polar fronts. Here, spiraling low-pressure cells known as depressions (mid-latitude cyclones) often form. A depression usually contains a sector of warmer air, beginning at a warm front and ending at a cold front. If the two fronts merge, forming an occluded front, the warm air is pushed upward. An extreme form of low-pressure cell is a hurricane (also called a typhoon or tropical cyclone), which brings torrential rain and exceptionally strong winds.

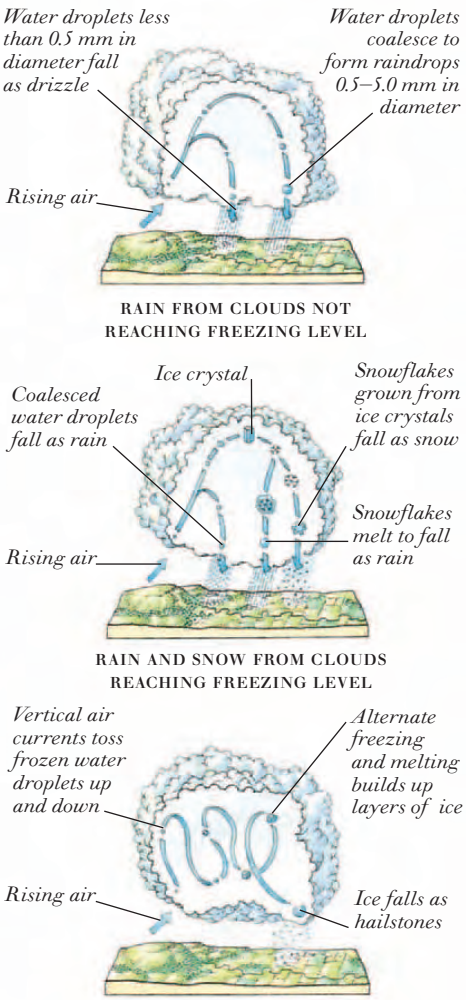
TYPES OF CLOUD



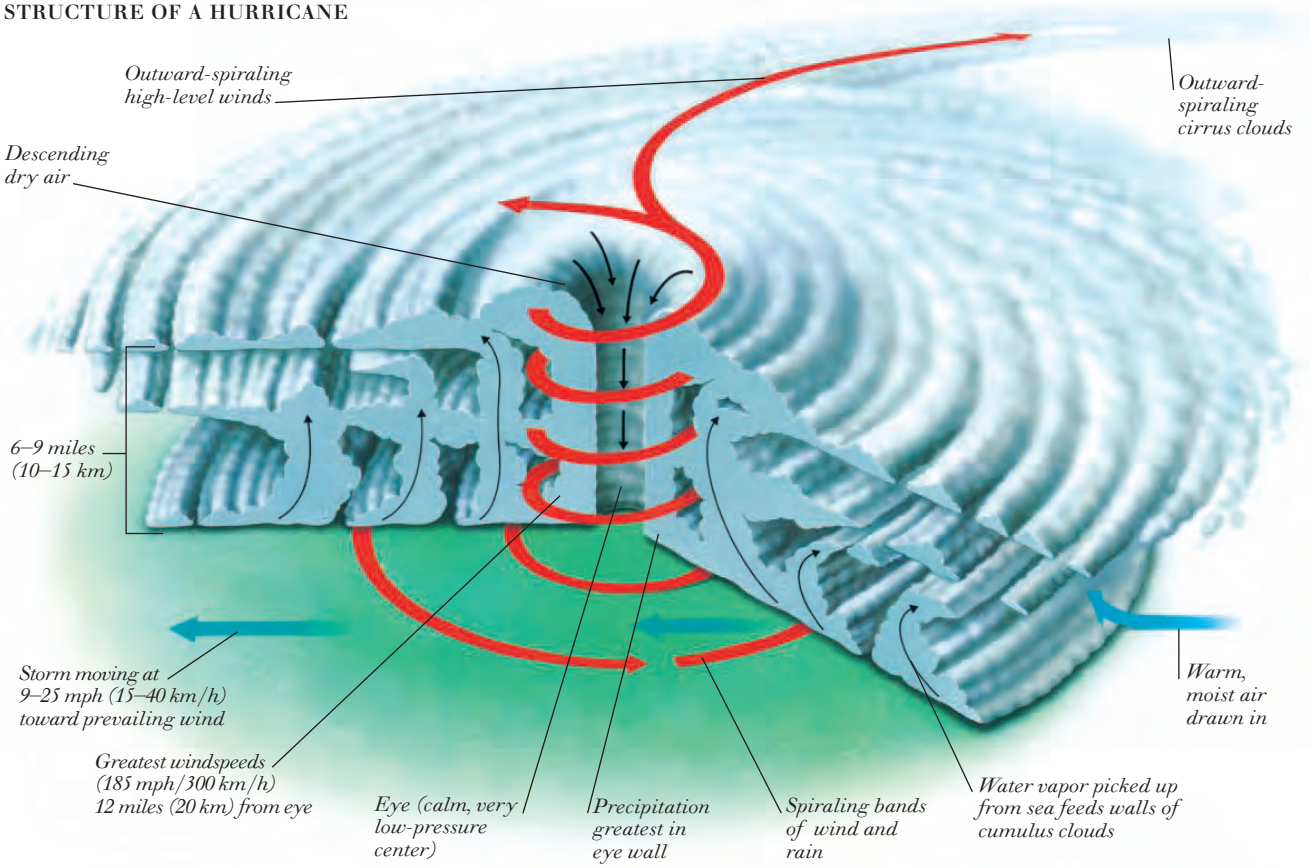
TYPES OF OCCLUDED FRONT



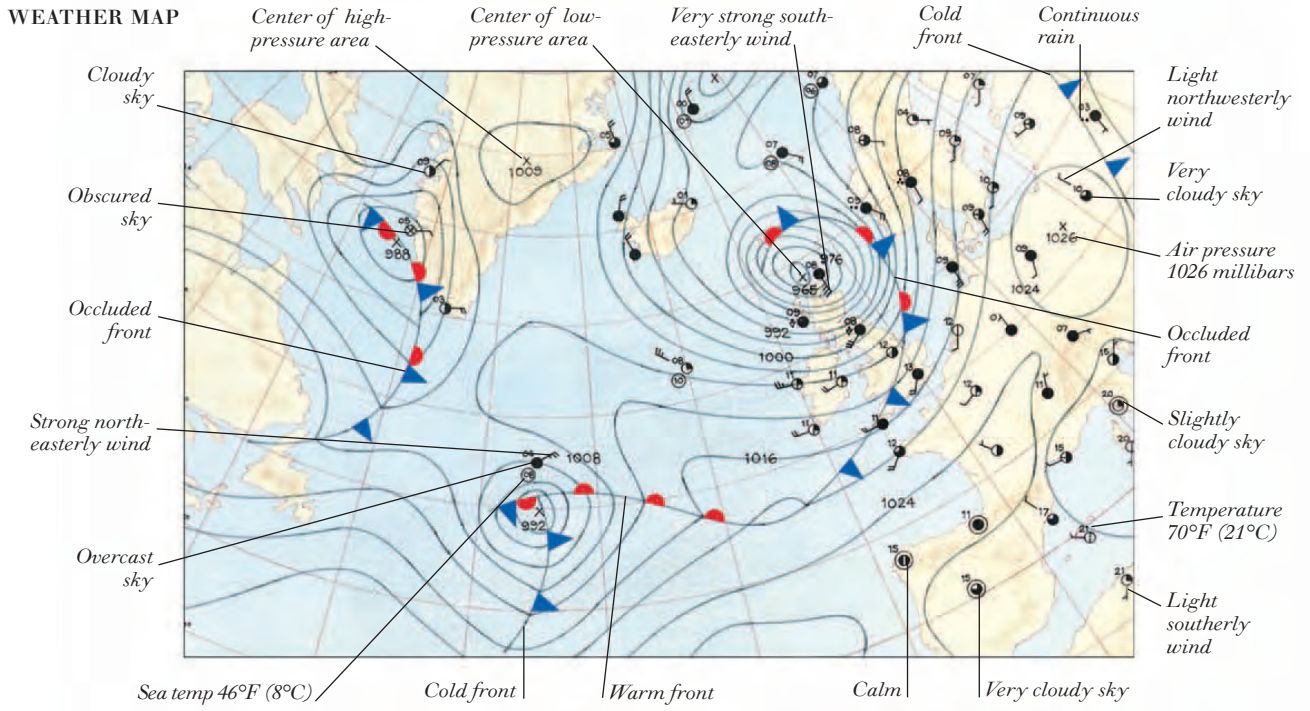
FORMS OF PRECIPITATION

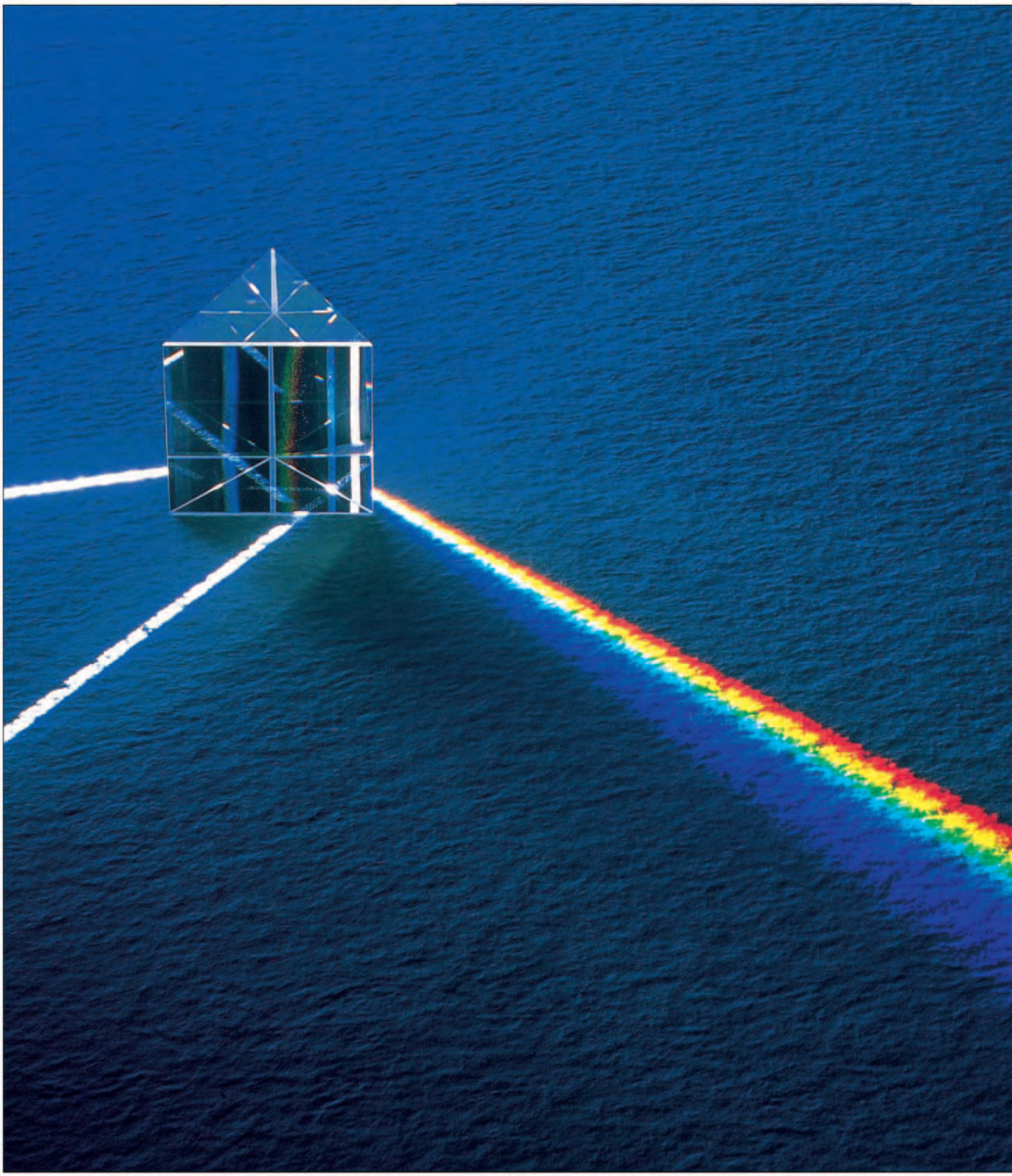


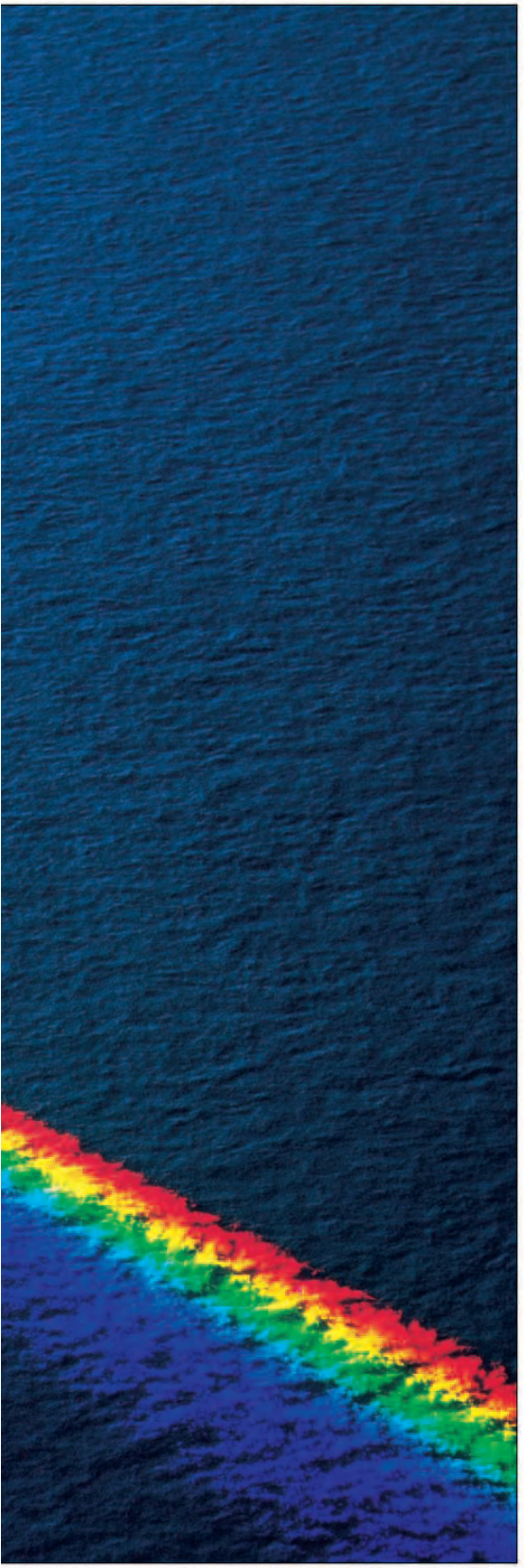
STRUCTURE OF A HURRICANE



WEATHER MAP







Physics and Chemistry

The Variety of Matter 306
Atoms and Molecules 308
The Periodic Table 310
Chemical Reactions 312
Energy 314
Electricity and Magnetism 316
Light 318
Force and Motion 320

The variety of matter

PLANT AND INSECT
(LIVING MATTER)

MATTER IS ANYTHING THAT HAS A MASS. It includes everything from natural substances, such as minerals or living organisms, to synthetic materials. Matter can exist in three distinct states—solid, liquid, and gas. A solid is rigid and retains its shape. A liquid is fluid, has a definite volume, and will take the shape of its container. A gas (also fluid) fills a space, so its volume will be the same as the volume of its container. Most substances can exist as a solid, a liquid, or a gas: the state is determined by temperature. At very high temperatures, matter becomes plasma, often considered to be a fourth state of matter. All matter is composed of microscopic particles, such as atoms and molecules (see pp. 308-309). The arrangement and interactions of these particles give a substance its physical and chemical properties, by which matter can be identified. There is a huge variety of matter because particles can arrange themselves in countless ways, in one substance or by mixing with others. Natural glass, for example, seems to be a solid but is, in fact, a supercool liquid: the atoms are not locked into a pattern and can flow. Pure substances known as elements (see p. 310) combine to form compounds or mixtures. Mixtures called colloids are made up of larger particles of matter suspended in a solid, liquid, or gas, while a solution is one substance dissolved in another.

TYPES OF COLLOID

HAIR GEL (SOLID IN LIQUID)

SHAVING CREAM
(AIR IN LIQUID)

MIST
(LIQUID IN GAS)

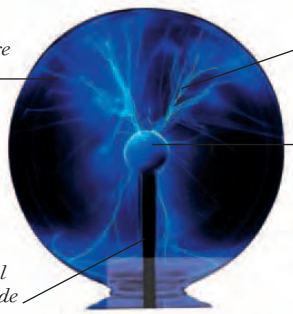
EXAMPLES OF MATTER

Poly-ethylene combines natural materials in new ways

POLYETHYLENE
(SYNTHETIC POLYMER)

The element silicon in pure crystalline form

PURE SILICON
(SEMICONDUCTOR)



Low pressure gases

Streaks of plasma (mixture of electrons and charged atoms)

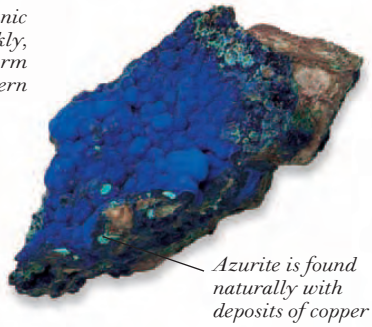
Voltage tears electrons from atoms of low pressure gases inside

Central electrode

BALL CONTAINING
HIGH-TEMPERATURE GAS
(PLASMA)

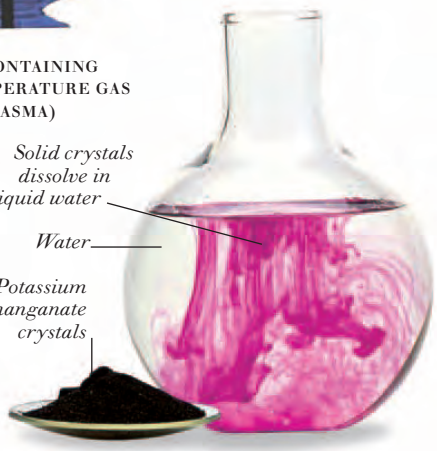
Obsidian is molten volcanic rock that cools quickly, so atoms cannot form a regular pattern

OBSIDIAN
(NATURAL GLASS)



Azurite is found naturally with deposits of copper ore

AZURITE
(CRYSTALLINE MINERAL)



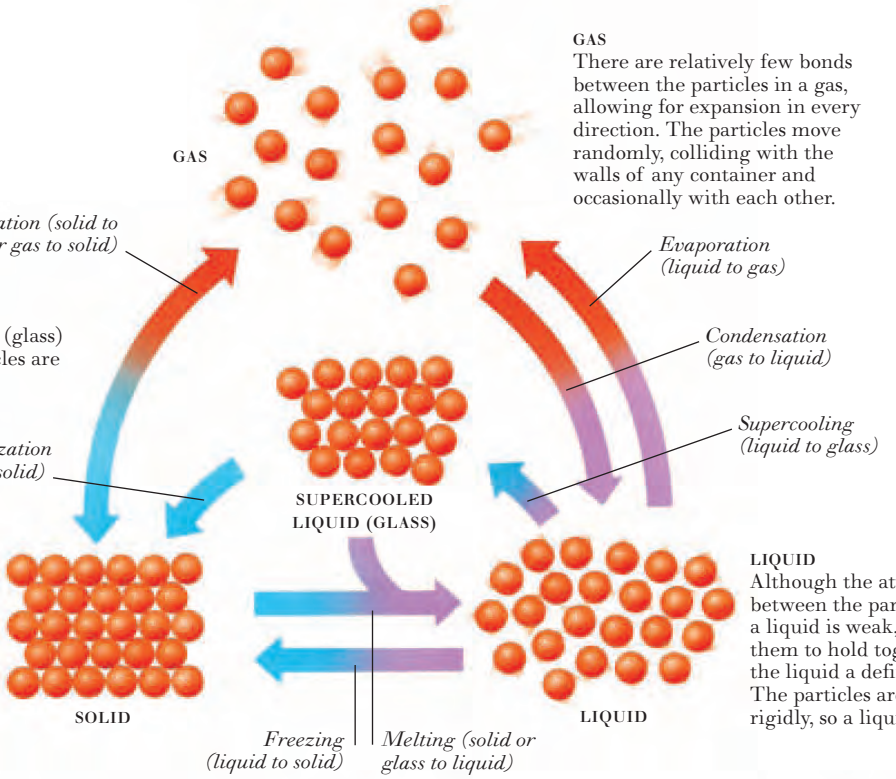
Solid crystals dissolve in liquid water

Water

Potassium permanganate crystals

POTASSIUM PERMANGANATE AND WATER
(SOLUTION)

STATES OF MATTER



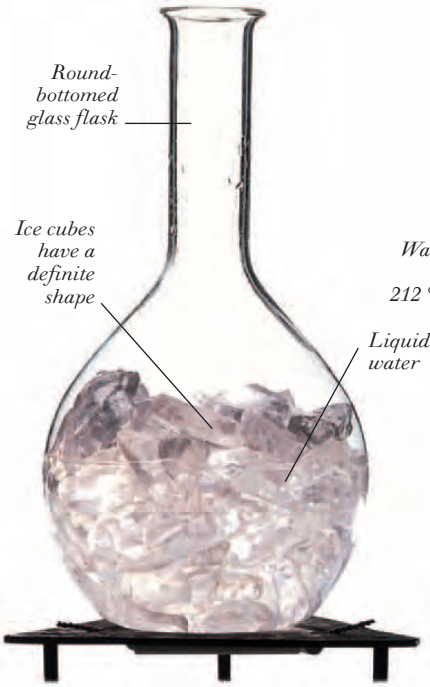
GAS
There are relatively few bonds between the particles in a gas, allowing for expansion in every direction. The particles move randomly, colliding with the walls of any container and occasionally with each other.

GLASS
A supercooled liquid (glass) is rigid, but its particles are arranged randomly.

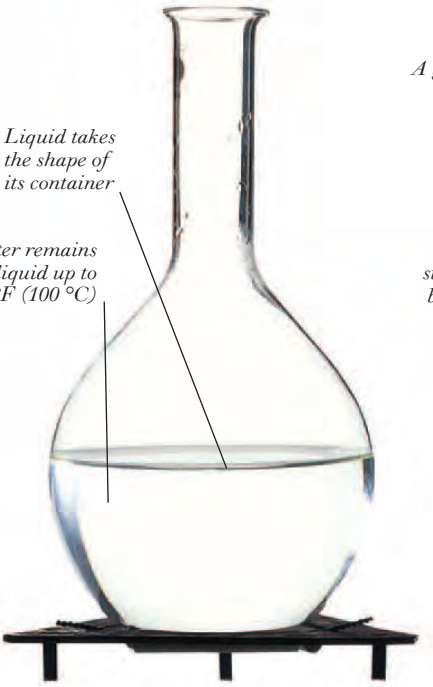
SOLID
Held together by strong forces, the particles of a solid maintain a constant position in relation to each other. Most solids are crystals, in which particles arrange in repeating patterns.

LIQUID
Although the attraction between the particles of a liquid is weak, it allows them to hold together to give the liquid a definite volume. The particles are not held rigidly, so a liquid flows.

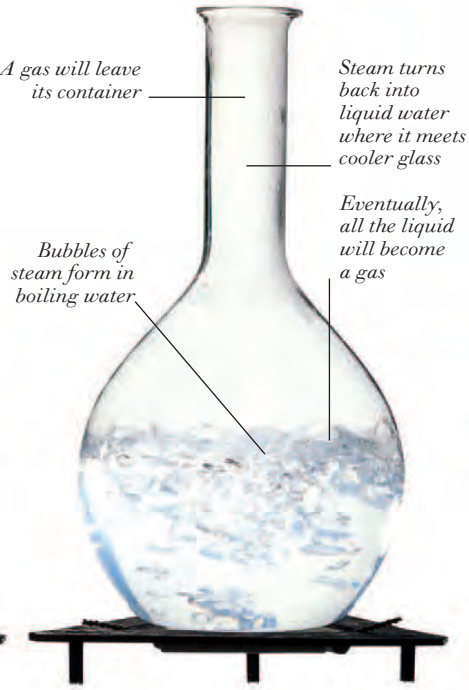
CHANGING STATES OF WATER



SOLID STATE: ICE
The solid state of water, ice, forms when liquid water is cooled sufficiently. Ice cubes are rigid, with a definite shape and volume.

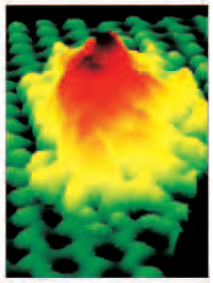


LIQUID STATE: WATER
When the temperature of a substance rises above its freezing point, it melts to become a liquid. Ice changes to water.



GASEOUS STATE: STEAM
Above its boiling point, a substance will become a gas. When heated sufficiently, liquid water turns to steam, a colorless gas.

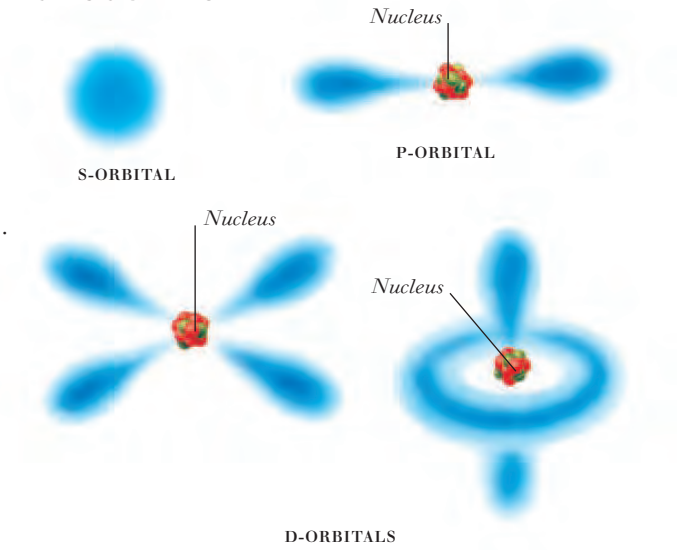
Atoms and molecules



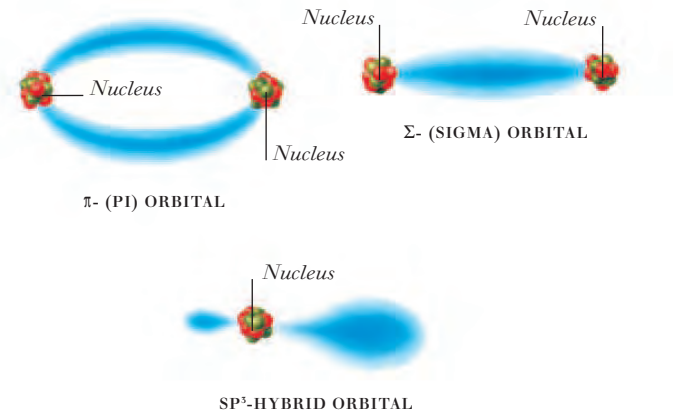
FALSE-COLOR IMAGE OF ACTUAL GOLD ATOMS

ATOMS ARE THE smallest individual parts of an element (see pp. 310-311). They are tiny, with diameters in the order of one ten-thousand-millionth of a meter (10^{-10} m). Two or more atoms join together (bond) to form a molecule of a substance known as a compound. For example, when atoms of the elements hydrogen and fluorine join together, they form a molecule of the compound hydrogen fluoride. So molecules are the smallest individual parts of a compound. Atoms themselves are not indivisible—they possess an internal structure. At their center is a dense nucleus, consisting of protons, which have a positive electric charge (see p. 316), and neutrons, which are uncharged. Around the nucleus are the negatively charged electrons. It is the electrons that give a substance most of its physical and chemical properties. They do not follow definite paths around the nucleus. Instead, electrons are said to be found within certain regions, called orbitals. These are arranged around the nucleus in "shells," each containing electrons of a particular energy. For example, the first shell (1) can hold up to two electrons, in a so-called s-orbital (1s). The second shell (2) can hold up to eight electrons, in s-orbitals (2s) and p-orbitals (2p). If an atom loses an electron, it becomes a positive ion (cation). If an electron is gained, an atom becomes a negative ion (anion). Ions of opposite charges will attract and join together, in a type of bonding known as ionic bonding. In covalent bonding, the atoms bond by sharing their electrons in what become molecular orbitals.

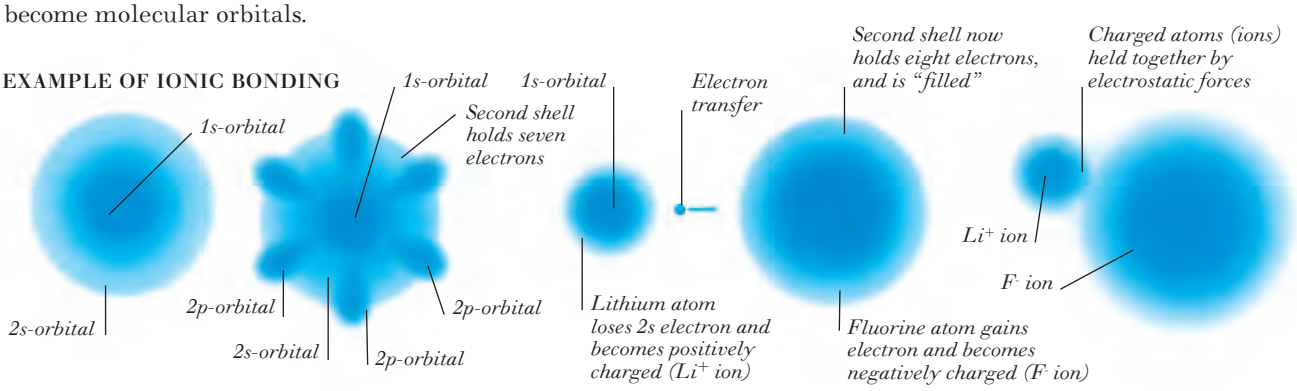
ATOMIC ORBITALS



MOLECULAR ORBITALS



EXAMPLE OF IONIC BONDING



1. NEUTRAL LITHIUM ATOM (Li)

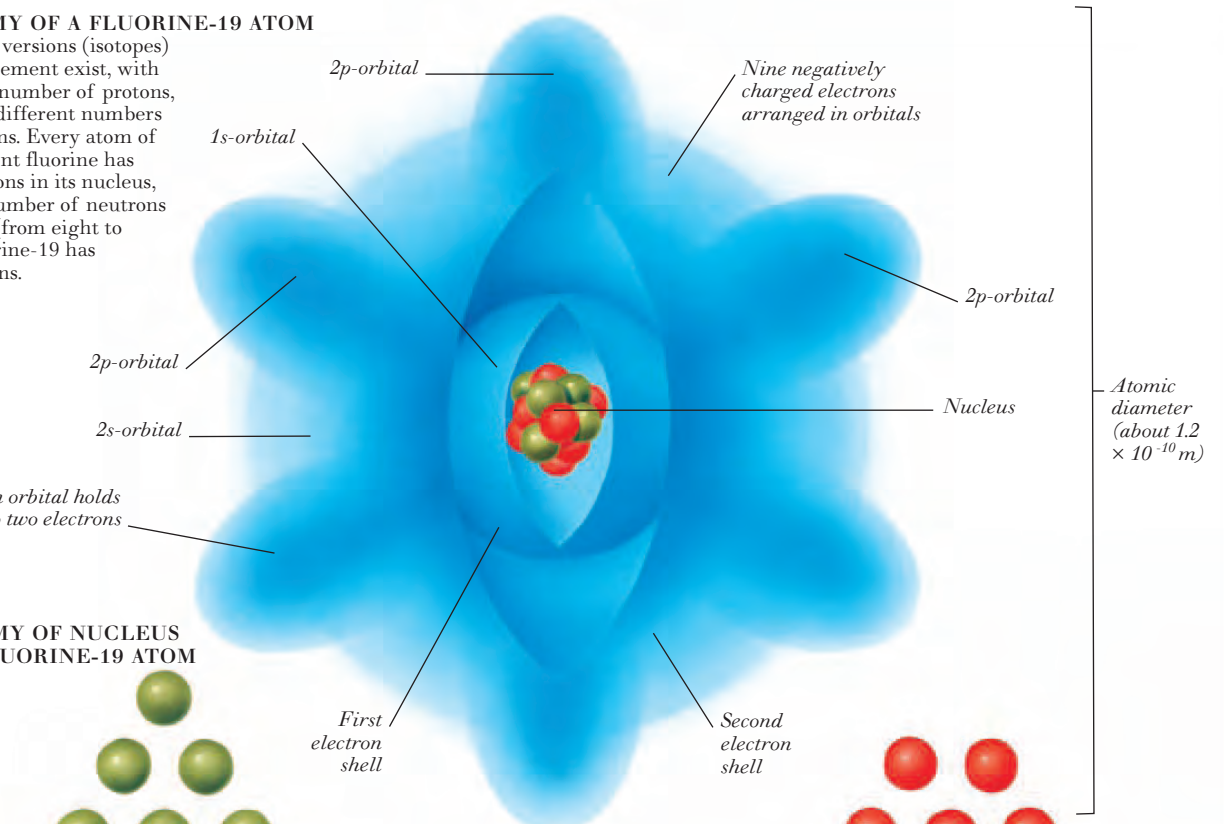
NEUTRAL FLUORINE ATOM (F)

2. ELECTRON TRANSFER

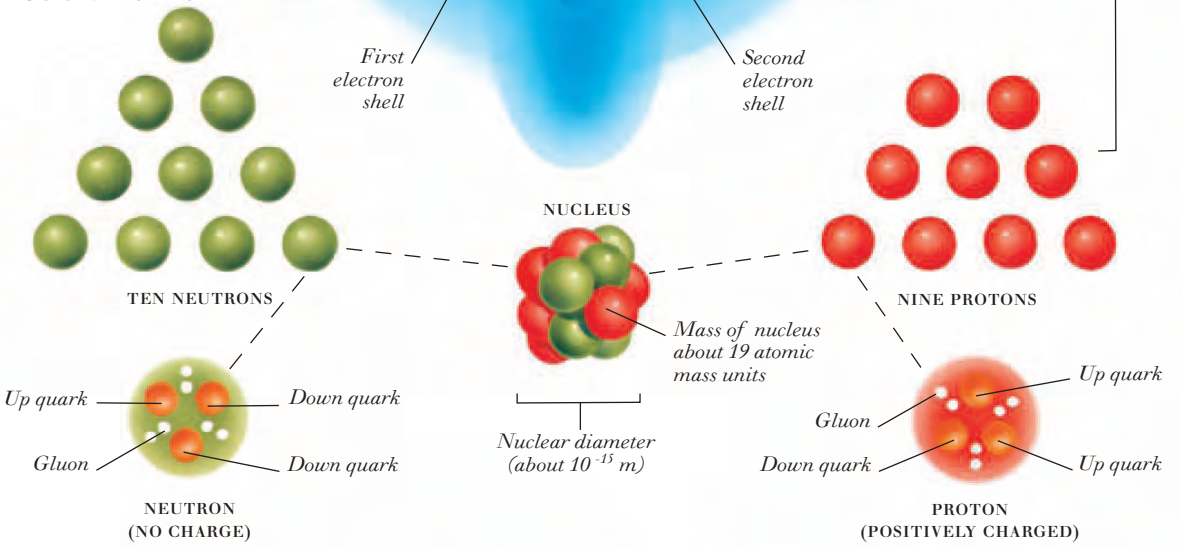
3. IONIC BONDING: LITHIUM FLUORIDE MOLECULE (LiF)

ANATOMY OF A FLUORINE-19 ATOM

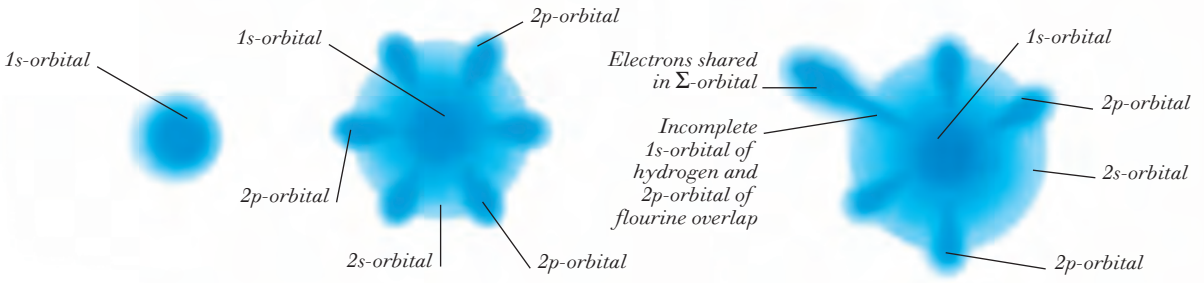
Different versions (isotopes) of each element exist, with the same number of protons, but with different numbers of neutrons. Every atom of the element fluorine has nine protons in its nucleus, but the number of neutrons can vary (from eight to 11). Fluorine-19 has 10 neutrons.



ANATOMY OF NUCLEUS OF A FLUORINE-19 ATOM

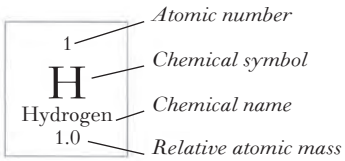


EXAMPLE OF COVALENT BONDING

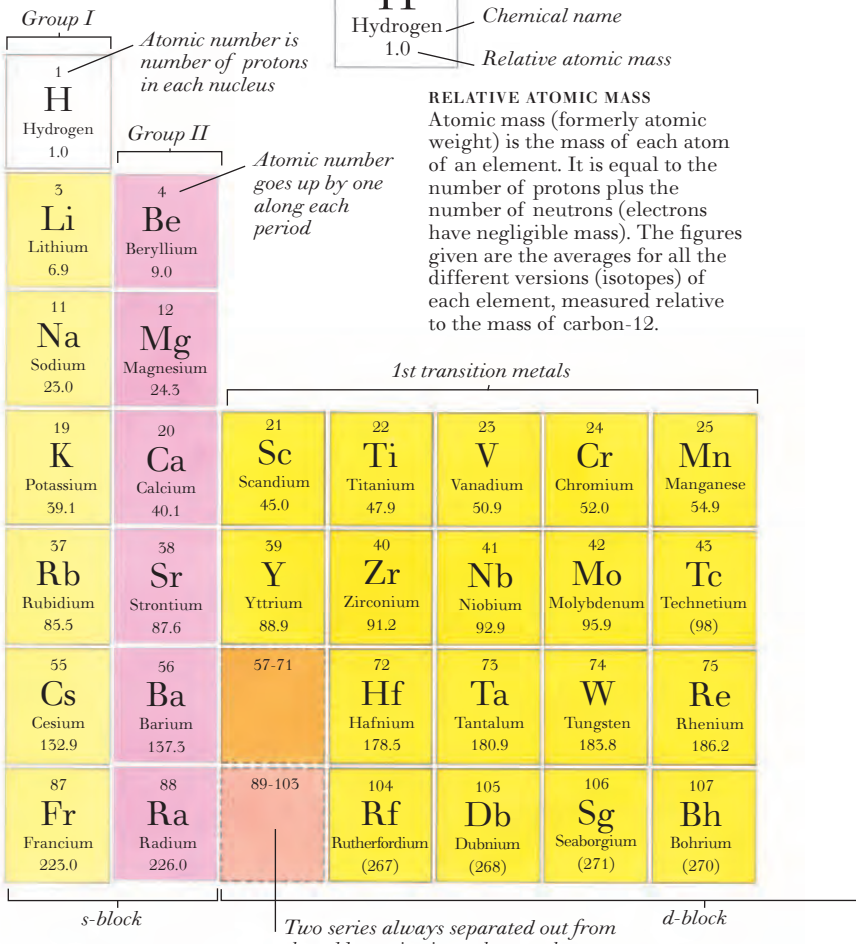


The periodic table

AN ELEMENT is a substance that consists of atoms of one type only. The 92 elements that occur naturally, and the 17 elements created artificially, are often arranged into a chart called the periodic table. Each element is defined by its atomic number—the number of protons in the nucleus of each of its atoms (it is also the number of electrons present). Atomic number increases along each row (period) and down each column (group). The shape of the table is determined by the way in which electrons arrange themselves around the nucleus: the positioning of elements in order of increasing atomic number brings together atoms with a similar pattern of orbiting electrons (orbitals). These appear in blocks. Electrons occupy shells of a certain energy (see pp. 308-309). Periods are ordered according to the filling of successive shells with electrons, while groups reflect the number of electrons in the outer shell (valency electrons). These outer electrons are important—they decide the chemical properties of the atom. Elements that appear in the same group have similar properties because they have the same number of electrons in their outer shell. Elements in Group 0 have "filled shells," where the outer shell holds its maximum number of electrons, and are stable. Atoms of Group I elements have just one electron in their outer shell. This makes them unstable—and ready to react with other substances.

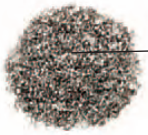


RELATIVE ATOMIC MASS
Atomic mass (formerly atomic weight) is the mass of each atom of an element. It is equal to the number of protons plus the number of neutrons (electrons have negligible mass). The figures given are the averages for all the different versions (isotopes) of each element, measured relative to the mass of carbon-12.

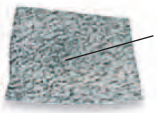


METALS AND NON-METALS
Elements at the left-hand side of each period are metals. Metals easily lose electrons and form positive ions. Non-metals, on the right of a period, tend to become negative ions. Semimetals, which have properties of both metals and non-metals, are between the two.

SODIUM: GROUP 1 METAL



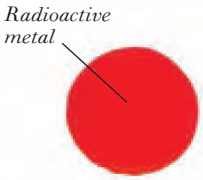
MAGNESIUM: GROUP 2 METAL



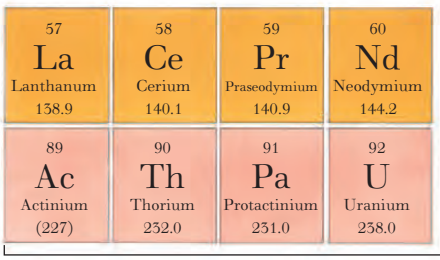
CHROMIUM: 1ST TRANSITION METAL

TYPES OF ELEMENT KEY:

- Alkali metals
- Alkaline earth metals
- Transition metals
- Lanthanides
- Actinides
- Poor metals
- Semi-metals
- Non-metals
- Noble gases
- Unknown chemical properties



PLUTONIUM: ACTINIDE SERIES METAL



DIAMOND

ALLOTROPES OF CARBON
Some elements exist in more than one form—these are known as allotropes. Carbon powder, graphite, and diamond are allotropes of carbon. They all consist of carbon atoms, but have very different physical properties.

GRAPHITE

CARBON POWDER

Bright yellow crystal

SULFUR: GROUP 6 SOLID NON-METAL

Purple-black solid turns to gas easily

IODINE: GROUP 7 SOLID NON-METAL

Group 0

Boron and carbon groups — *Group III*, *Group IV*

Nitrogen and oxygen groups — *Group V*, *Group VI*

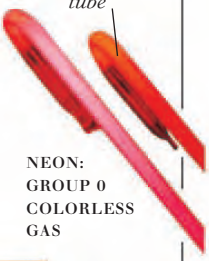
Halogens — *Group VII*

2nd transition metals — *3rd transition metals*

					5 B Boron 10.8	6 C Carbon 12.0	7 N Nitrogen 14.0	8 O Oxygen 16.0	9 F Fluorine 19.0	2 He Helium 4.0	*Period*
										10 Ne Neon 20.2	*Short period*
					13 Al Aluminum 27.0	14 Si Silicon 28.1	15 P Phosphorus 31.0	16 S Sulfur 32.1	17 Cl Chlorine 35.5	18 Ar Argon 40.0	
26 Fe Iron 55.8	27 Co Cobalt 58.9	28 Ni Nickel 58.7	29 Cu Copper 63.5	30 Zn Zinc 65.4	31 Ga Gallium 69.7	32 Ge Germanium 72.6	33 As Arsenic 74.9	34 Se Selenium 79.0	35 Br Bromine 79.9	36 Kr Krypton 83.8	*Long period*
44 Ru Ruthenium 101.1	45 Rh Rhodium 102.9	46 Pd Palladium 106.4	47 Ag Silver 107.9	48 Cd Cadmium 112.4	49 In Indium 114.8	50 Sn Tin 118.7	51 Sb Antimony 121.8	52 Te Tellurium 127.6	53 I Iodine 126.9	54 Xe Xenon 131.3	
76 Os Osmium 190.2	77 Ir Iridium 192.2	78 Pt Platinum 195.1	79 Au Gold 197.0	80 Hg Mercury 200.6	81 Tl Thallium 204.4	82 Pb Lead 207.2	83 Bi Bismuth 209.0	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)	
108 Hs Hassium (269)	109 Mt Meitnerium (278)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (281)	112 Cn Copernicium (285)	113 Uut Ununtrium (286)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (289)	116 Uuh Ununhexium (293)	117 Uus Ununseptium (294)	118 Uuo Ununoctium (294)	

d-block *p-block*

Unreactive, colorless gas glows red in discharge tube



NEON: GROUP 0 COLORLESS GAS

NOBLE GASES
Group 0 contains elements that have a filled (complete) outer shell of electrons, which means the atoms do not need to lose or gain electrons by bonding with other atoms. This makes them stable and they do not easily form ions or react with other elements. Noble gases are also called rare or inert gases.

Yellow, unreactive precious metal

GOLD: 3RD TRANSITION METAL

Soft, shiny, reactive metal

TIN: GROUP 4 POOR METAL

Shiny semi-metal

ANTIMONY: GROUP 5 SEMI-METAL

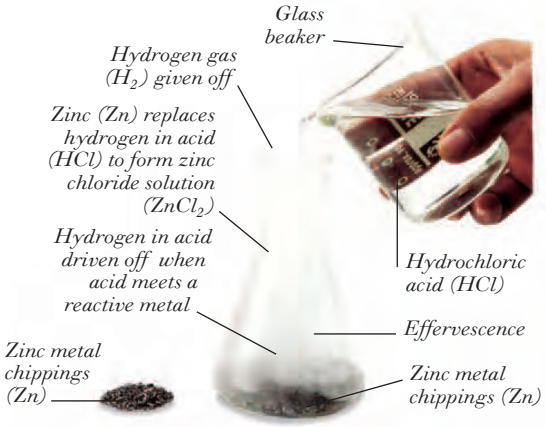
61 Pm Promethium (145)	62 Sm Samarium 150.4	63 Eu Europium 152.0	64 Gd Gadolinium 157.3	65 Tb Terbium 158.9	66 Dy Dysprosium 162.5	67 Ho Holmium 164.9	68 Er Erbium 167.3	69 Tm Thulium 168.9	70 Yb Ytterbium 173.0	71 Lu Lutetium 175.0
93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

f-block

Chemical reactions

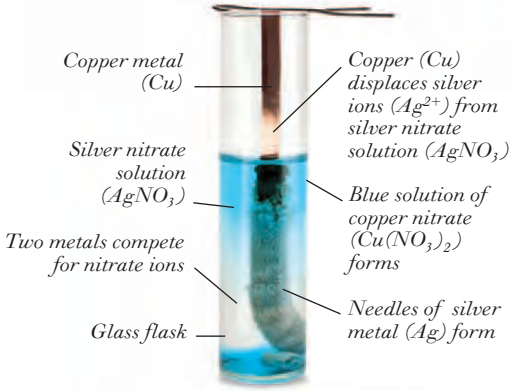
A CHEMICAL REACTION TAKES PLACE whenever bonds between atoms are broken or made. In each case, atoms or groups of atoms rearrange, making new substances (products) from the original ones (reactants). Reactions happen naturally, or can be made to happen; they may take years, or only an instant. Some of the main types are shown here. A reaction usually involves a change in energy (see pp. 314-315). In a burning reaction, for example, the making of new bonds between atoms releases energy as heat and light. This type of reaction, in which heat is given off, is an exothermic reaction. Many reactions, like burning, are irreversible, but some can take place in either direction, and are said to be reversible. Reactions can be used to form solids from solutions: in a double decomposition reaction, two compounds in solution break down and re-form into two new substances, often creating a precipitate (insoluble solid); in displacement, an element (e.g., copper) displaces another element (e.g., silver) from a solution. The rate (speed) of a reaction is determined by many different factors, such as temperature, and the size and shape of the reactants. To describe and keep track of reactions, internationally recognized chemical symbols and equations are used. Reactions are also used in the laboratory to identify matter. An experiment with candle wax, for example, demonstrates that it contains carbon and hydrogen.

SALT FORMATION (ACID ON METAL)



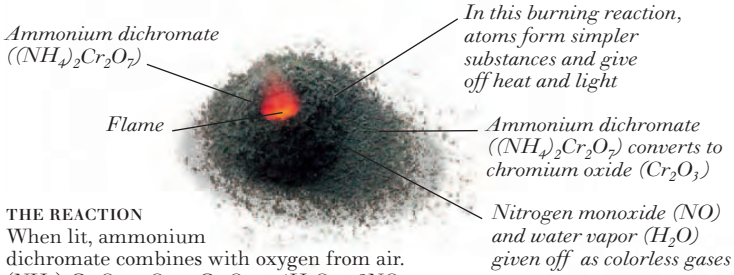
THE REACTION
Hydrochloric acid added to zinc produces zinc chloride and hydrogen.
$Zn + 2HCl \rightarrow ZnCl_2 + H_2$

DISPLACEMENT



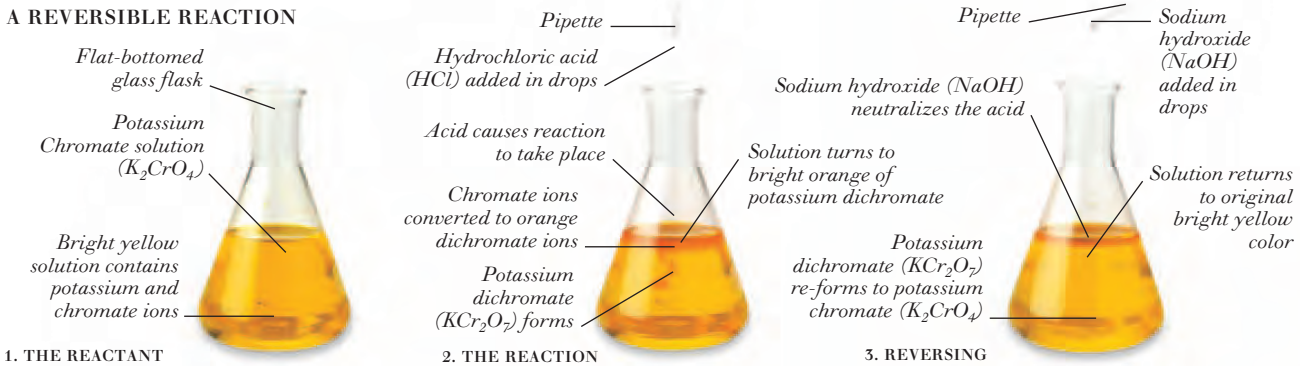
THE REACTION
Copper metal added to silver nitrate solution produces copper nitrate and silver metal.
$Cu + 2AgNO_5 \rightarrow Cu(NO_5)_2 + 2Ag$

BURNING MATTER



THE REACTION
When lit, ammonium dichromate combines with oxygen from air.
$(NH_4)_2Cr_2O_7 + O_2 \rightarrow Cr_2O_3 + 4H_2O + 2NO$

A REVERSIBLE REACTION

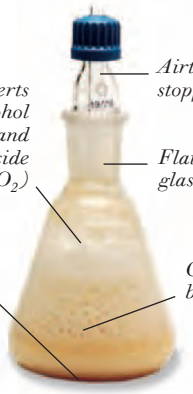


1. THE REACTANT
Potassium chromate dissolves in water to form potassium ions and chromate ions.
$K_2CrO_4 \rightarrow 2K^+ + CrO_4^{2-}$

2. THE REACTION
Addition of hydrochloric acid changes chromate ions into dichromate ions.
$2CrO_4^{2-} \rightarrow Cr_2O_7^{2-}$

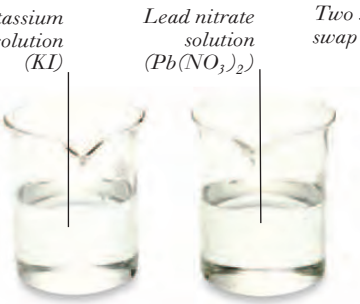
3. REVERSING
Addition of sodium hydroxide changes dichromate ions back into chromate ions.
$Cr_2O_7^{2-} \rightarrow 2CrO_4^{2-}$

FERMENTATION



THE REACTION
Yeast converts sugar and warm water into alcohol and carbon dioxide.
$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

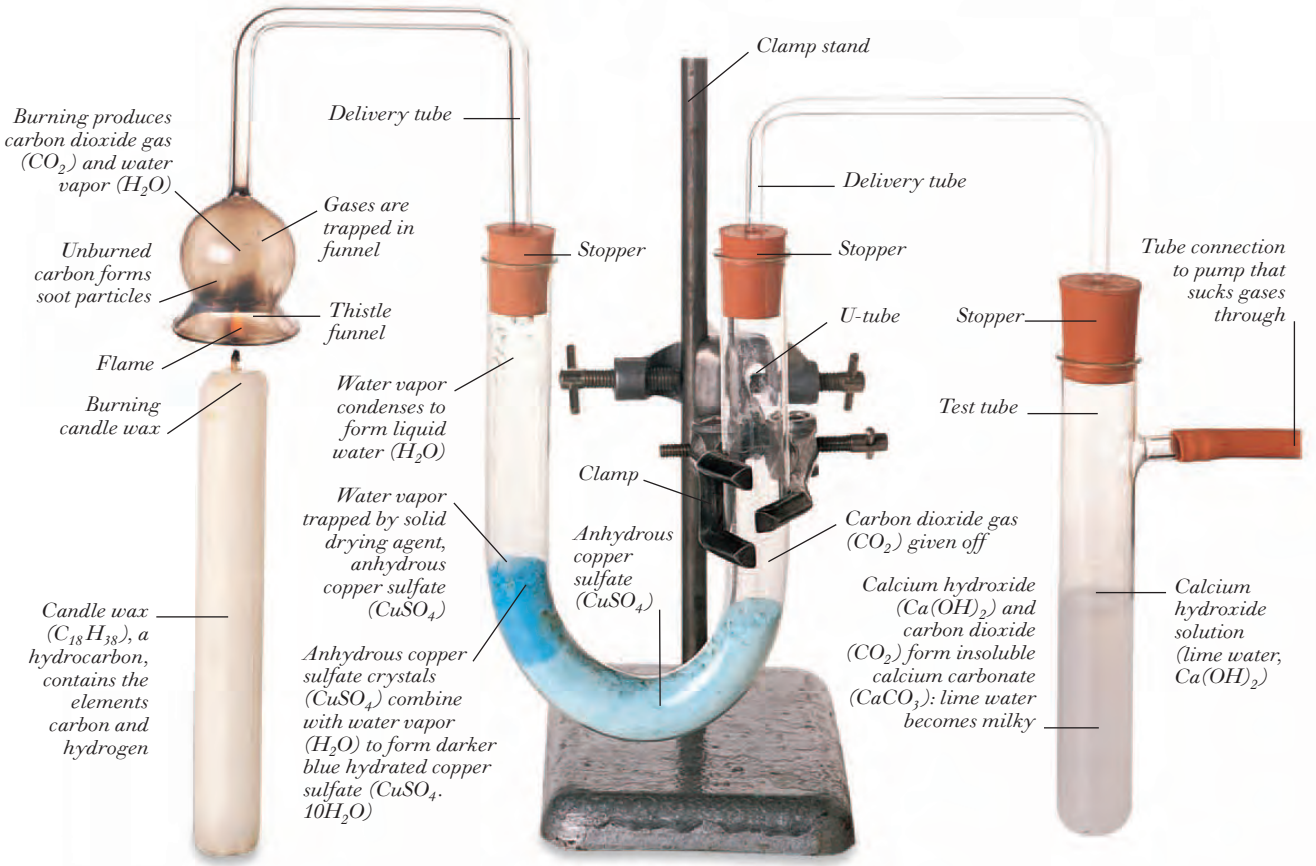
DOUBLE DECOMPOSITION



1. THE REACTANTS
Potassium iodide in water (KI) and lead nitrate in water ($Pb(NO_3)_2$) each form colorless solutions.

2. THE REACTION
When the solutions are mixed, lead iodide, a precipitate, and potassium nitrate solution are formed.
$2KI + Pb(NO_3)_2 \rightarrow PbI_2 + 2KNO_3$

TESTING CANDLE WAX, AN ORGANIC COMPOUND



1. THE BURNING REACTION
Burning wax produces carbon dioxide gas and water vapor.
$2C_{18}H_{58} + 55O_2 \rightarrow 36CO_2 + 38H_20$

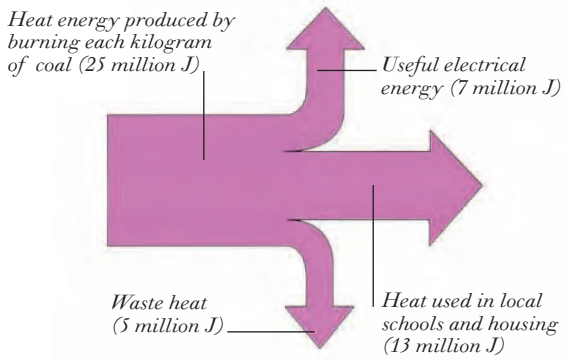
2. TESTING FOR WATER VAPOR
A solid drying agent traps water vapor, proving the presence of hydrogen in the candle wax.
$CuSO_4 + 10H_2O \rightarrow CuSO_4 . 10H_2O$

3. TESTING FOR CARBON DIOXIDE
Calcium hydroxide in solution reacts with carbon dioxide, forming a carbonate and turning milky.
$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

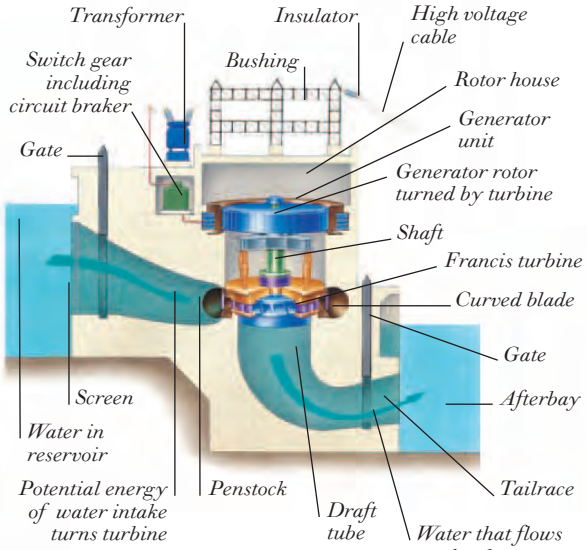
Energy

ANYTHING THAT HAPPENS—from a pin-drop to an explosion—requires energy. Energy is the capacity for "doing work" (making something happen). Various forms of energy exist, including light, heat, sound, electrical, chemical, nuclear, kinetic, and potential energies. The Law of Conservation of Energy states that the total amount of energy in the universe is fixed—energy cannot be created or destroyed. It means that energy can only change from one form to another (energy transfer). For example, potential energy is energy that is "stored," and can be used in the future. An object gains potential energy when it is lifted; as the object is released, potential energy changes into the energy of motion (kinetic energy). During transference, some of the energy converts into heat. A combined heat and power station can put some of the otherwise "waste" heat to useful effect in local schools and housing. Most of the Earth's energy is provided by the Sun, in the form of electromagnetic radiation (see pp. 316-317). Some of this energy transfers to plant and animal life, and ultimately to fossil fuels, where it is stored in chemical form. Our bodies obtain energy from the food we eat, while energy needed for other tasks, such as heating and transport, can be obtained by burning fossil fuels—or by harnessing natural forces like wind or moving water—to generate electricity. Another source is nuclear power, where energy is released by reactions in the nucleus of an atom. All energy is measured by the international unit, the joule (J). As a guide, one joule is about equal to the amount of energy needed to lift an apple one meter.

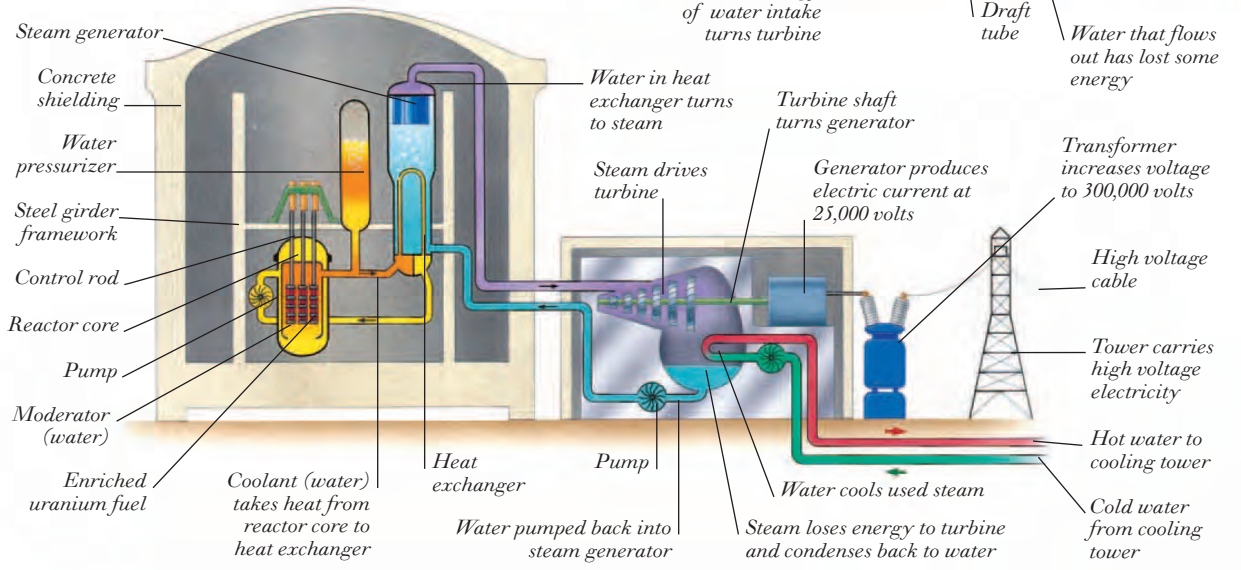
SANKEY DIAGRAM SHOWING ENERGY FLOW IN A COAL-FIRED COMBINED HEAT AND POWER STATION



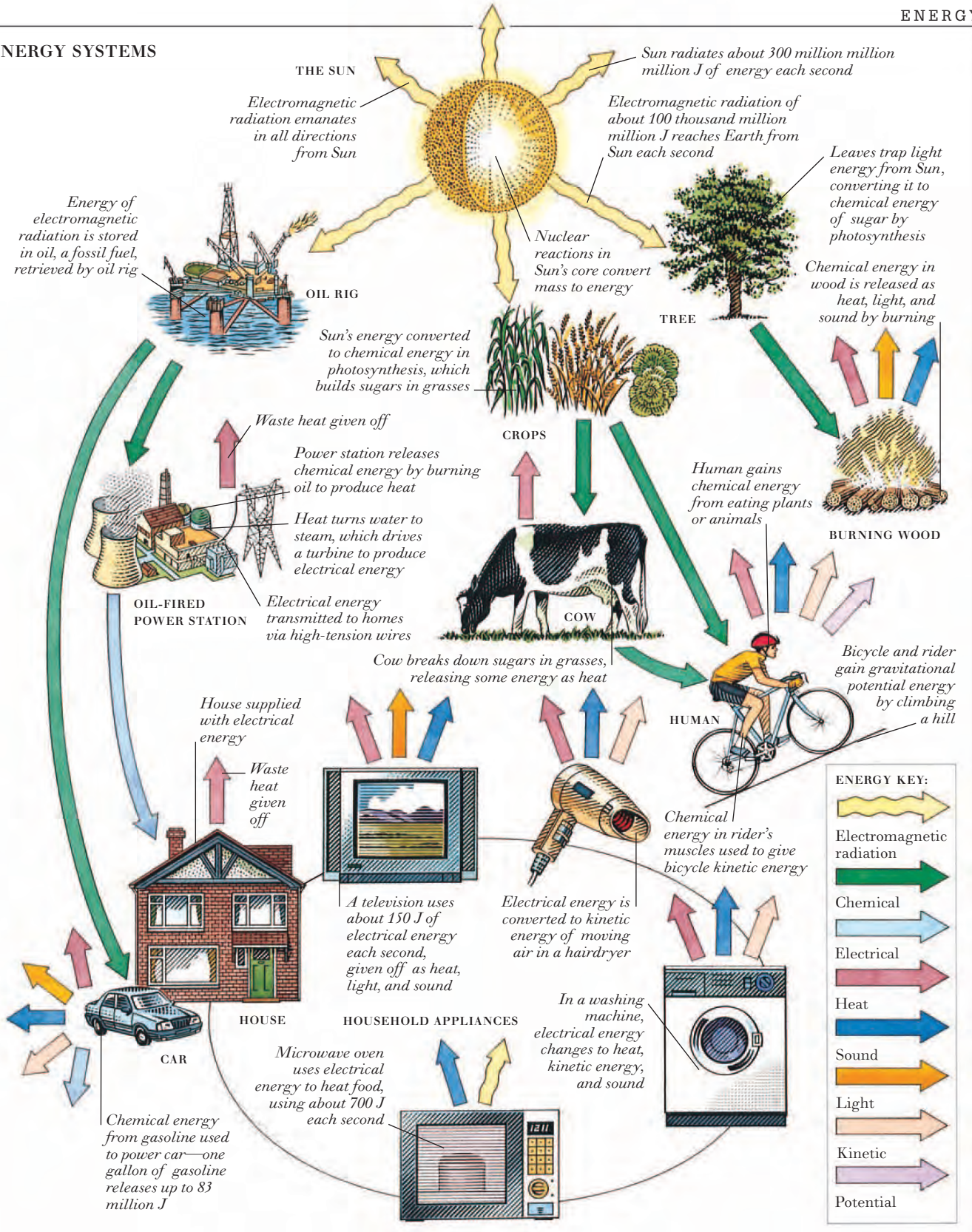
CROSS-SECTION OF HYDROELECTRIC POWER STATION WITH FRANCIS TURBINE



CROSS-SECTION OF NUCLEAR POWER STATION WITH PRESSURIZED WATER REACTOR



ENERGY SYSTEMS

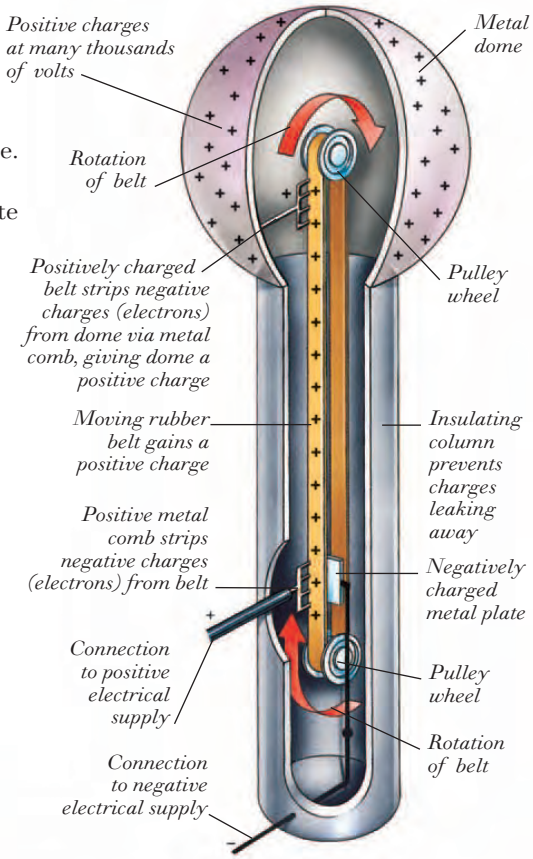


Electricity and magnetism

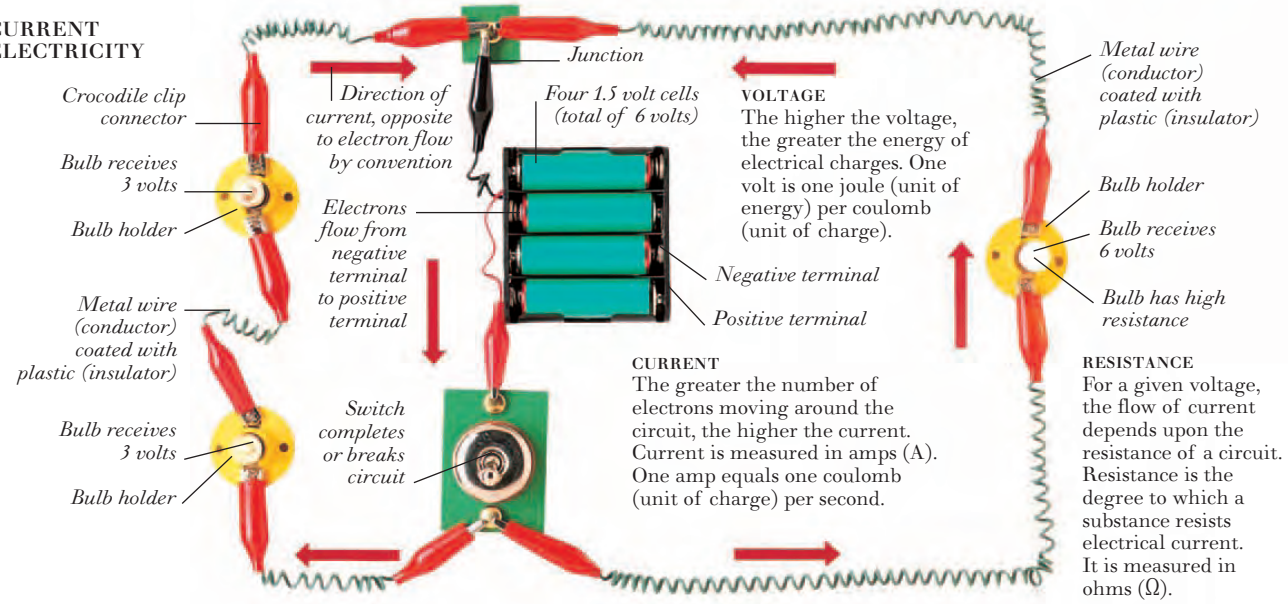
ELECTRICAL EFFECTS result from an imbalance of electric charge. There are two types of electric charge, named positive (carried by protons) and negative (carried by electrons). If charges are opposite (unlike), they attract one another, while like charges repel. Forces of attraction and repulsion (electrostatic forces) exist between any two charged particles. Matter is normally uncharged, but if electrons are gained, an object will gain an overall negative charge; if they are removed, it becomes positive. Objects with an overall negative or positive charge are said to have an imbalance of charge, and exert the same forces as individual negative and positive charges. On this larger scale, the forces will always act to regain the balance of charge. This causes static electricity. Lightning, for example, is produced by clouds discharging a huge excess of negative electrons. If charges are "free"—in a wire or material that allows electrons to pass through it—the forces cause a flow of charge called an electric current. Some substances exhibit the strange phenomenon of magnetism—which also produces attractive and repulsive forces. Magnetic substances consist of small regions called domains. Normally unmagnetized, they can be magnetized by being placed in a magnetic field. Magnetism and electricity are inextricably linked, a fact put to use in motors and generators.

LIGHTNING

VAN DE GRAAFF (ELECTROSTATIC) GENERATOR



CURRENT ELECTRICITY



VOLTAGE
The higher the voltage, the greater the energy of electrical charges. One volt is one joule (unit of energy) per coulomb (unit of charge).

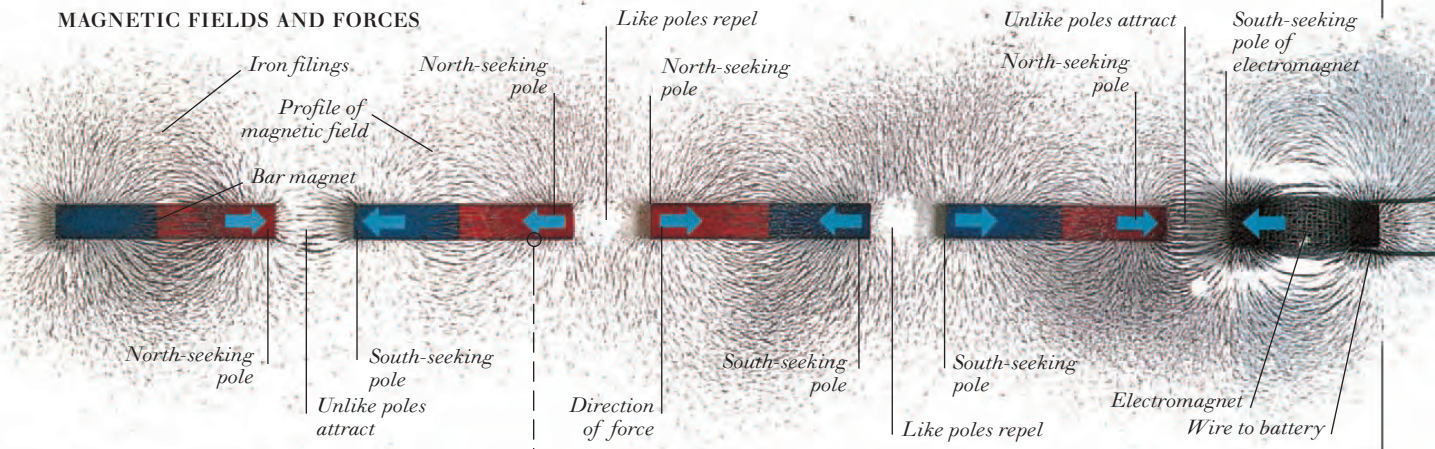
CURRENT
The greater the number of electrons moving around the circuit, the higher the current. Current is measured in amps (A). One amp equals one coulomb (unit of charge) per second.

RESISTANCE
For a given voltage, the flow of current depends upon the resistance of a circuit. Resistance is the degree to which a substance resists electrical current. It is measured in ohms (Ω).

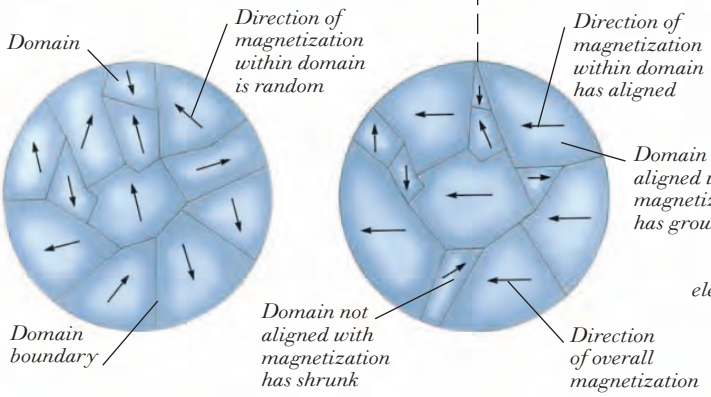
SERIES ELECTRICAL CIRCUIT

SIMPLE ELECTRICAL CIRCUIT

MAGNETIC FIELDS AND FORCES



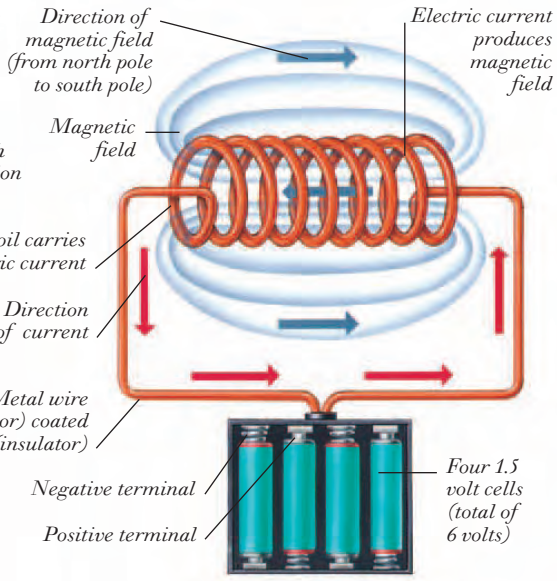
MAGNETIC DOMAINS



UNMAGNETIZED IRON

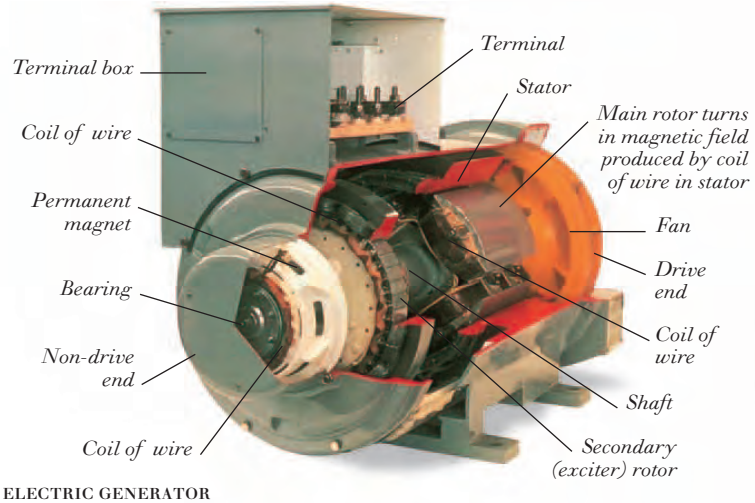
MAGNETIZED IRON IN A MAGNETIC FIELD

GENERATING MAGNETISM FROM ELECTRICITY



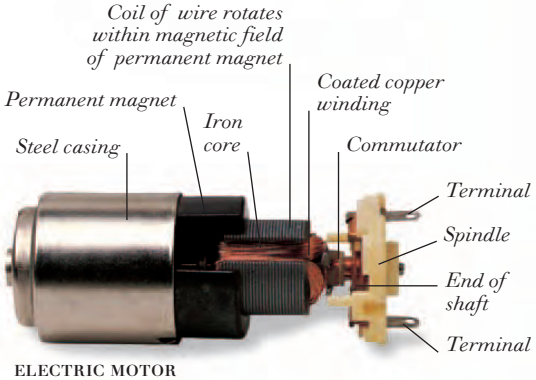
CIRCUIT WITH ELECTROMAGNET

GENERATING ELECTRICITY FROM MAGNETISM



ELECTRIC GENERATOR

In a generator, the rotor rotates within the magnetic field of the stator to produce an electric current.



ELECTRIC MOTOR

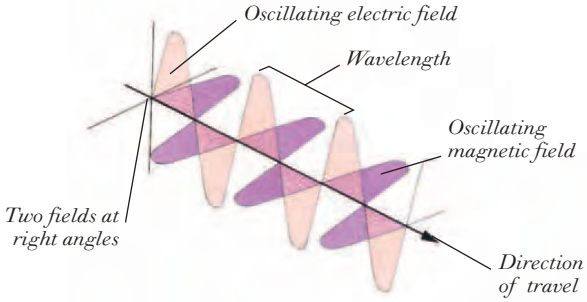
In a motor, magnetic forces between the winding and permanent magnet produce a rotary motion.

INFRARED IMAGE OF A HOUSE

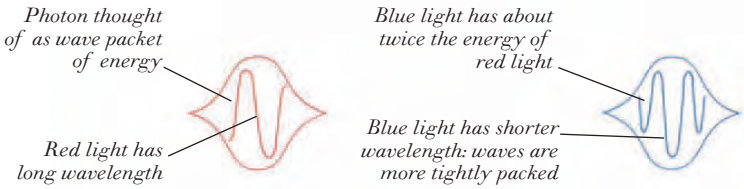
Light

LIGHT IS A FORM OF ENERGY. It is a type of electromagnetic radiation, like X-rays or radio waves. All electromagnetic radiation is produced by electric charges (see pp. 316-317): it is caused by the effects of oscillating electric and magnetic fields as they travel through space. Electromagnetic radiation is considered to have both wave and particle properties. It can be thought of as a wave of electricity and magnetism. In that case, the difference between the various forms of radiation is their wavelength. Radiation can also be said to consist of particles, or packets of energy, called photons. The difference between light and X-rays, for instance, is the amount of energy that each photon carries. The complete range of radiation is referred to as the electromagnetic spectrum, extending from low energy, long wavelength radio waves to high energy, short wavelength gamma rays. Light is the only part of the electromagnetic spectrum that is visible. White light from the Sun is made up of all the visible wavelengths of radiation, which can be seen when it is separated by using a prism. Light, like all forms of electromagnetic radiation, can be reflected (bounced back) and refracted (bent). Different parts of the electromagnetic spectrum are produced in different ways. Sometimes visible light—and infrared radiation—is generated by the vibrating particles of warm or hot objects. The emission of light in this way is called incandescence. Light can also be produced by fluorescence, a phenomenon in which electrons gain and lose energy within atoms.

MAXWELLIAN DIAGRAM OF ELECTROMAGNETIC RADIATION AS WAVES



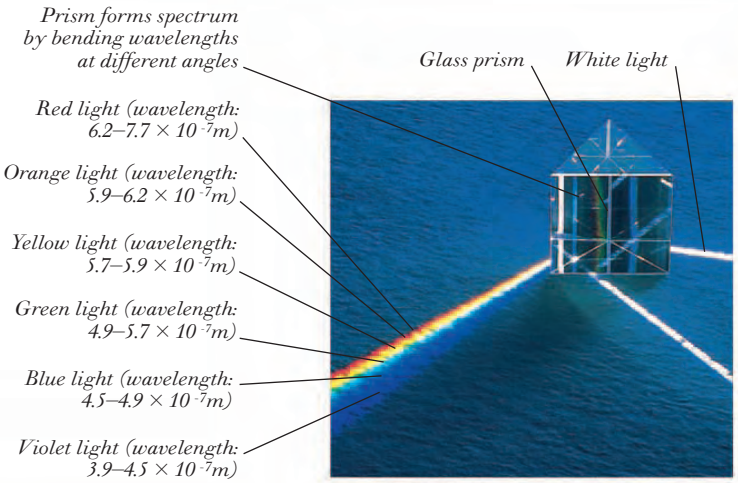
ELECTROMAGNETIC RADIATION AS PARTICLES



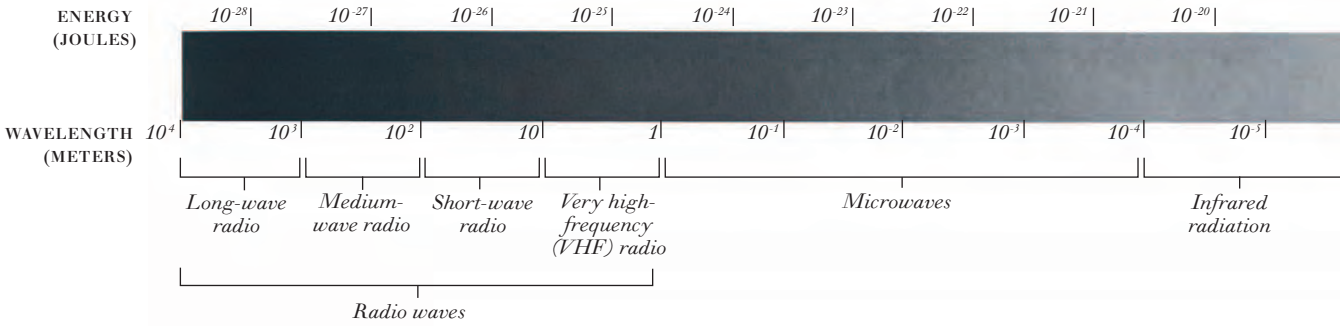
PHOTON OF RED LIGHT

PHOTON OF BLUE LIGHT

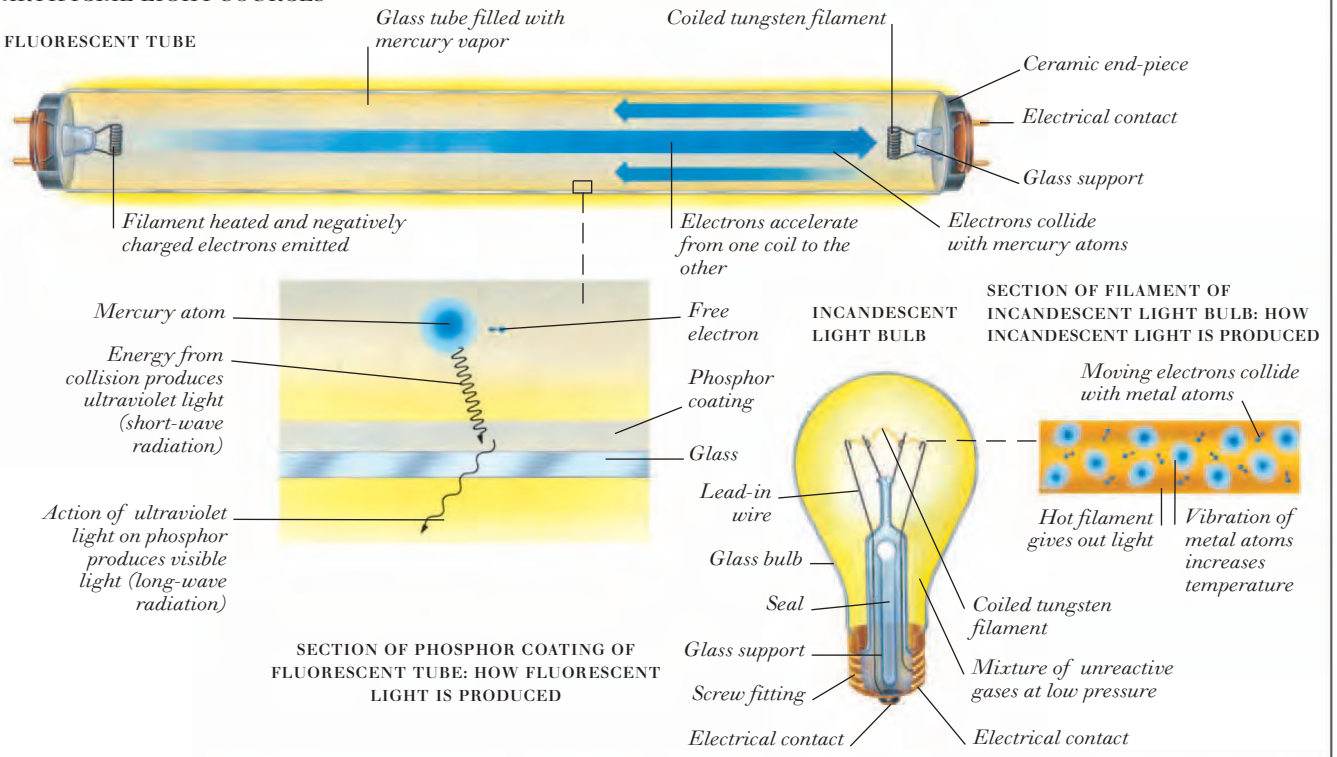
SPLITTING WHITE LIGHT INTO THE SPECTRUM



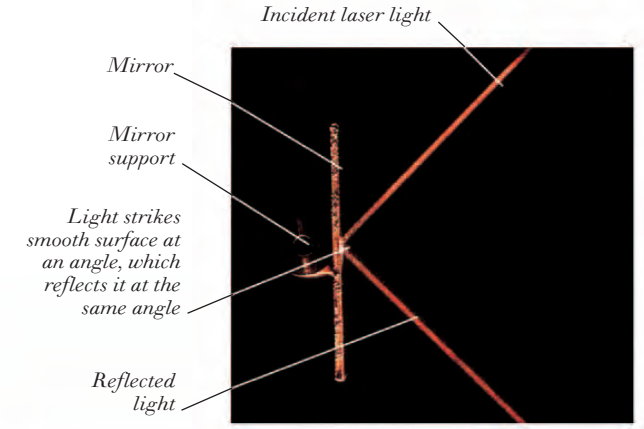
THE ELECTROMAGNETIC SPECTRUM



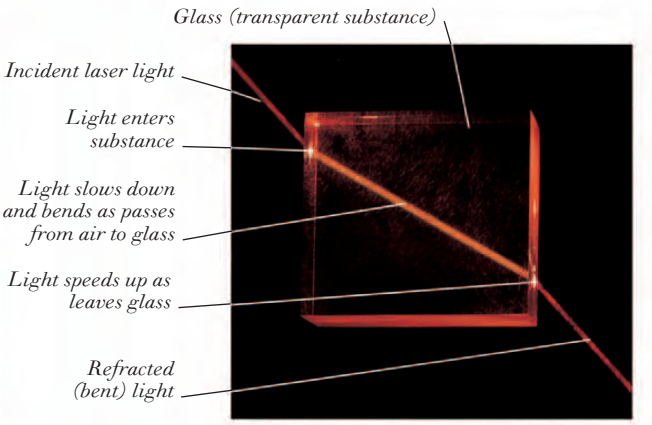
ARTIFICIAL LIGHT SOURCES

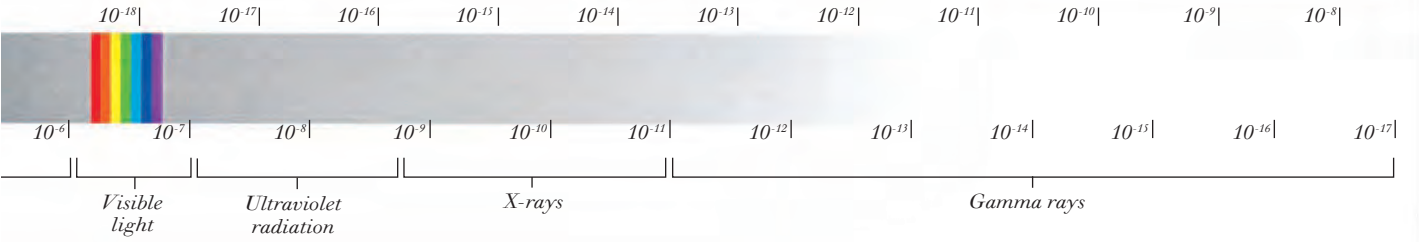


REFLECTION OF LIGHT



REFRACTION OF LIGHT

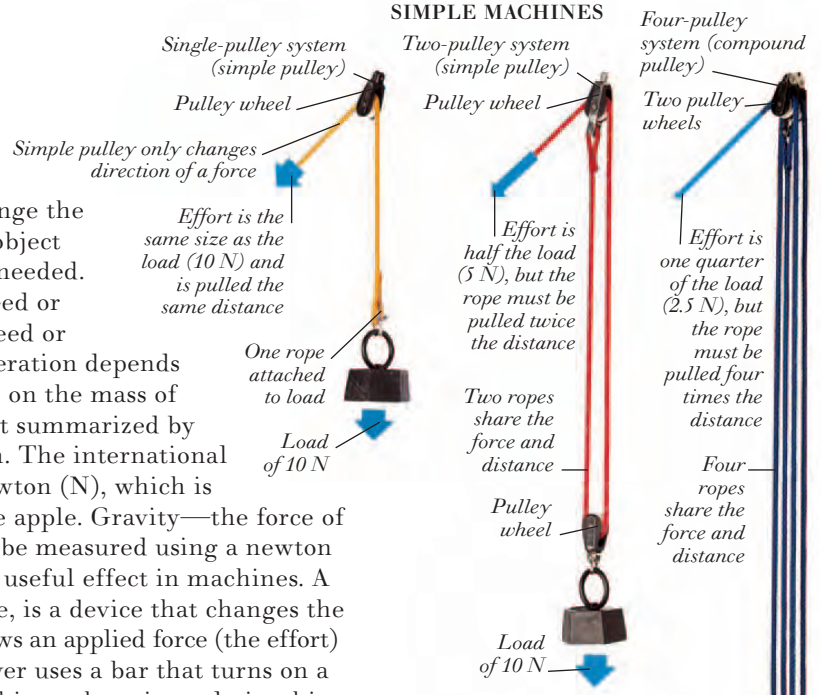




Force and motion

FORCES ARE PUSHES OR PULLS that change the motion of objects. To make a stationary object move, or a moving object stop, a force is needed. A force is also required to change the speed or direction of an object. This change in speed or direction is known as acceleration. Acceleration depends on the size (magnitude) of the force, and on the mass of the object. The effects of forces were first summarized by Isaac Newton in his three laws of motion. The international unit of force, named after him, is the newton (N), which is approximately equal to the weight of one apple. Gravity—the force of attraction between any two masses—can be measured using a newton meter (spring balance). Forces are put to useful effect in machines. A simple machine, such as a wheel and axle, is a device that changes the size or direction of an applied force. It allows an applied force (the effort) to produce another force (the load). A lever uses a bar that turns on a fulcrum to exert force. In all simple machines, there is a relationship between force and distance. A small force (in a compound pulley, for instance) moves through a large distance to lift a heavy object a small distance. This is called the Law of Simple Machines.

SIMPLE MACHINES

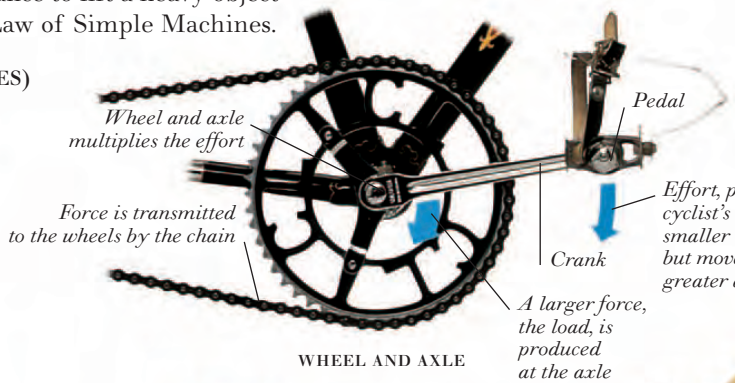


SIMPLE AND COMPOUND PULLEYS

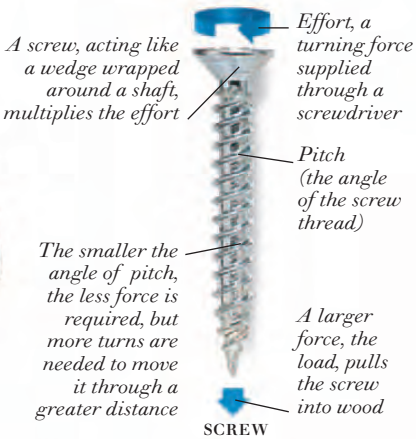
NEWTON METERS (SPRING BALANCES)

WEIGHT AND MASS

The "mass" of an object is a measure of the quantity of matter that it possesses. Mass is usually measured in grams (g) or kilograms (kg). The "weight" of an object is the force exerted on the object's mass by gravity. Since weight is a force, its unit is the newton (N).



WHEEL AND AXLE



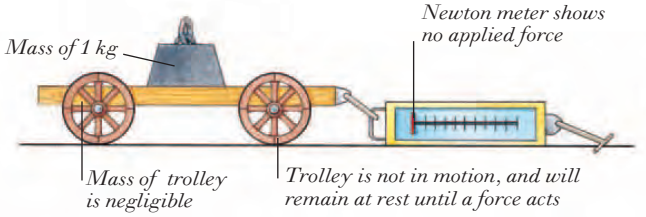
SCREW

WEDGE

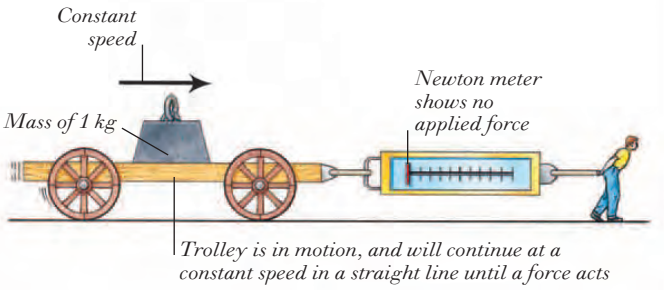
NEWTON'S THREE LAWS OF MOTION

NEWTON'S FIRST LAW

When no force acts on a body, it will continue in a state of rest or uniform motion.



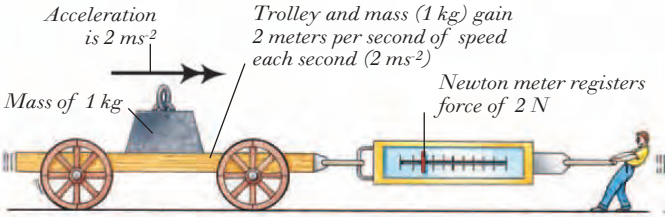
NO FORCE, NO ACCELERATION: STATE OF REST



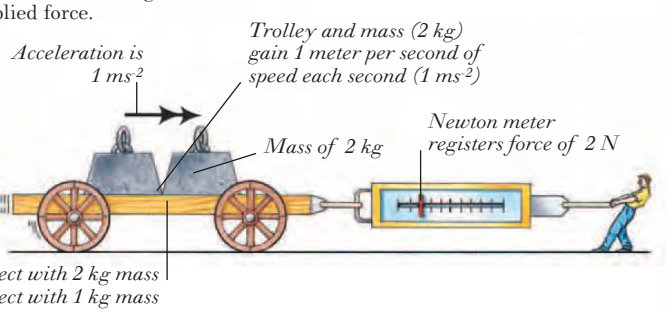
NO FORCE, NO ACCELERATION: UNIFORM MOTION

NEWTON'S SECOND LAW

When a force acts on a body, the motion of the body will change. The size of the change will depend upon the mass of the object and the magnitude of the applied force.



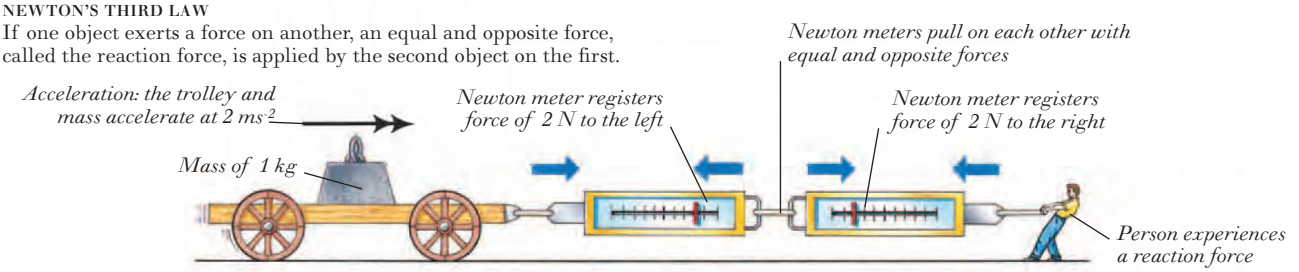
FORCE AND ACCELERATION: SMALL MASS, LARGE ACCELERATION



FORCE AND ACCELERATION: LARGE MASS, SMALL ACCELERATION

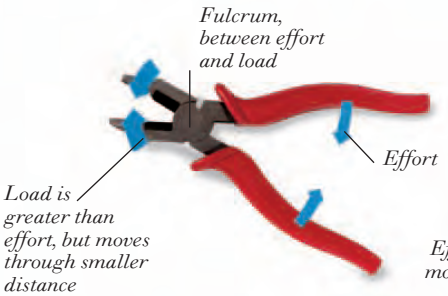
NEWTON'S THIRD LAW

If one object exerts a force on another, an equal and opposite force, called the reaction force, is applied by the second object on the first.

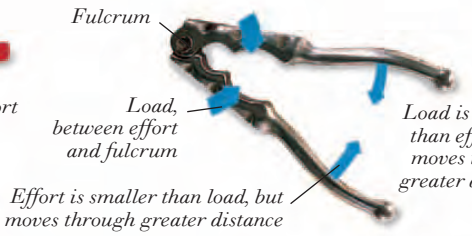


ACTION AND REACTION

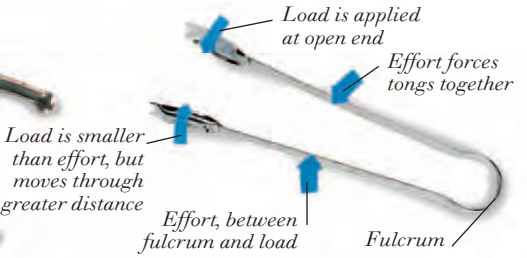
THREE CLASSES OF LEVER



CLASS 1 LEVER
Pliers consist of two class 1 levers.



CLASS 2 LEVER
Nutcrackers consist of two class 2 levers.



CLASS 3 LEVER
Tongs consist of two class 3 levers.

ELECTRIC

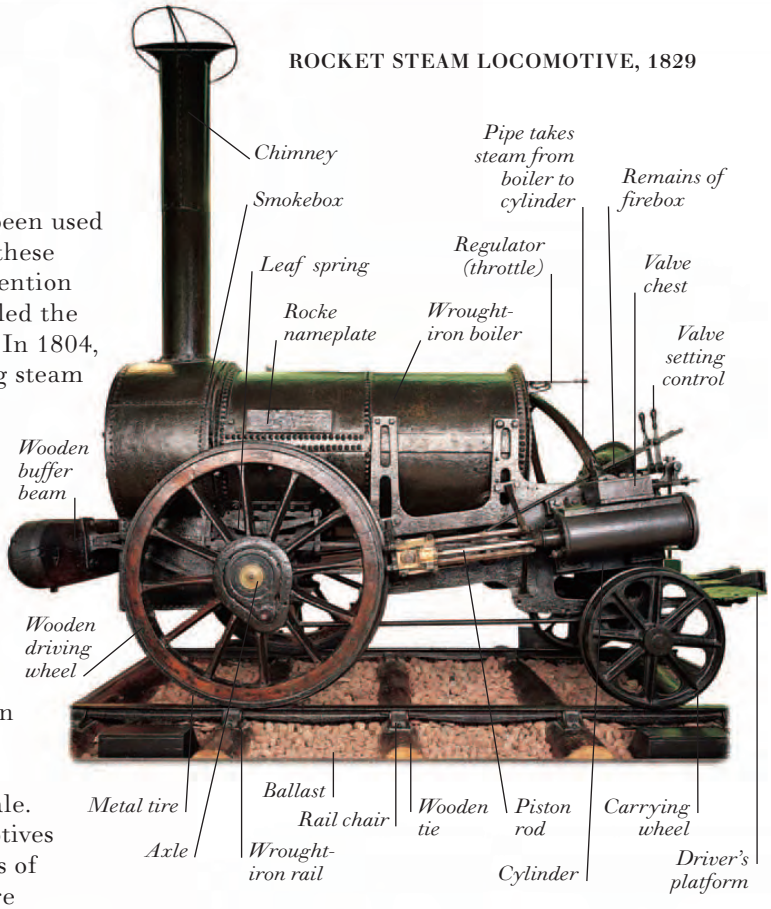
Rail and Road

Steam Locomotives 324
Diesel Trains 326
Electric and High-speed Trains 328
Train Equipment 330
Trolleys and Buses 332
The First Cars 334
Elegance and Utility 336
Mass-production 338
The "People's Car" 340
Early Engines 342
Modern Engines 344
Alternative Engines 346
Bodywork 348
Mechanical Components 350
Car Trim 352
Hybrid Car 354
Race Cars 356
Bicycle Anatomy 358
Bicycles 360
The Motorcycle 362
The Motorcycle Chassis 364
Motorcycle Engines 366
Competition Motorcycles 368

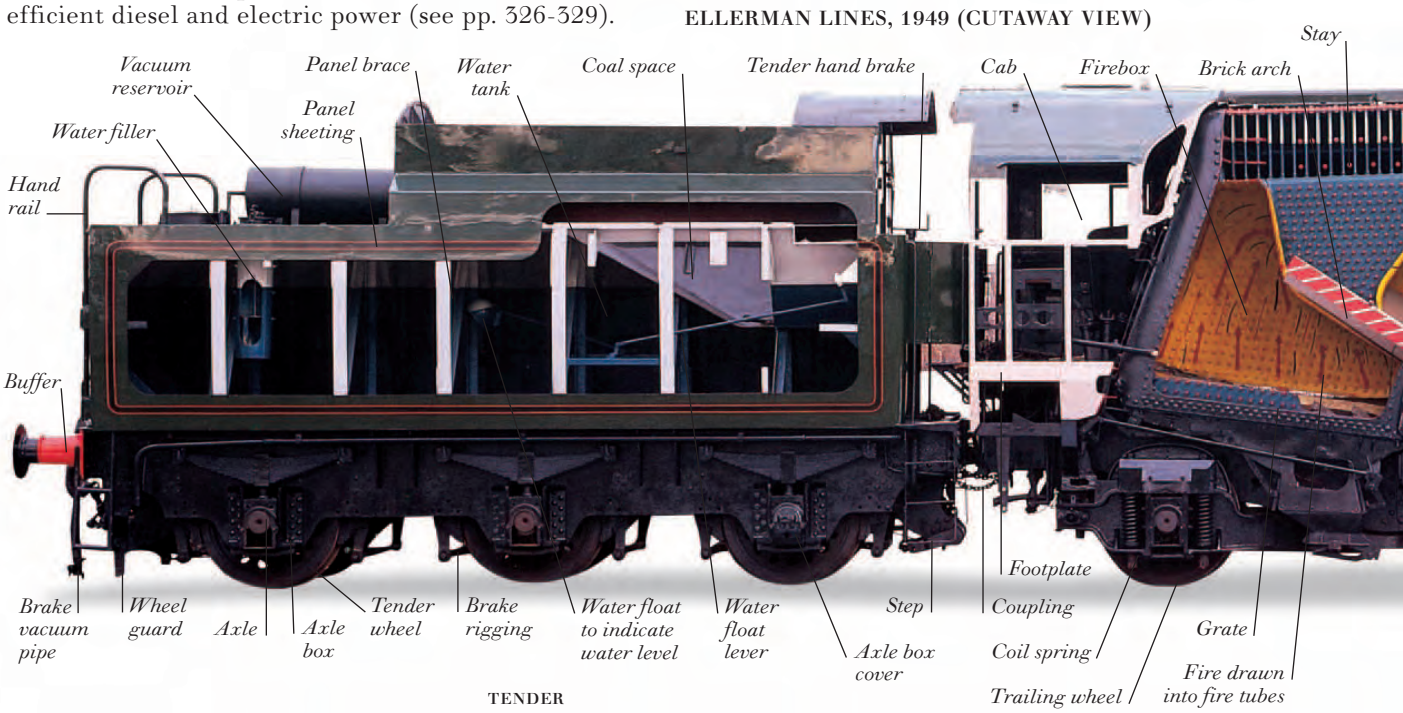
Steam locomotives

WAGONS THAT ARE PULLED along tracks have been used to transport material since the 16th century, but these trains were drawn by men or horses until the invention of the steam locomotive. Steam locomotives enabled the basic railroad system to realize its true potential. In 1804, Richard Trevithick built the world's first working steam locomotive in South Wales. It was not entirely successful, but it encouraged others to develop new designs. By 1829, the British engineer Robert Stephenson had built the Rocket, considered to be the forerunner of the modern locomotive. The Rocket was a self-sufficient unit, carrying coal to heat the boiler and a water supply for generating steam. Steam passed from the boiler to force the pistons back and forth, and this movement turned the driving wheels, propelling the train forward. Used steam was then expelled in characteristic puffs. Later steam locomotives, like Ellerman Lines and the Mallard, worked in a similar way, but on a much larger scale. The simple design and reliability of steam locomotives ensured that they changed very little in 120 years of use, before being replaced from the 1950s by more efficient diesel and electric power (see pp. 326-329).

ROCKET STEAM LOCOMOTIVE, 1829

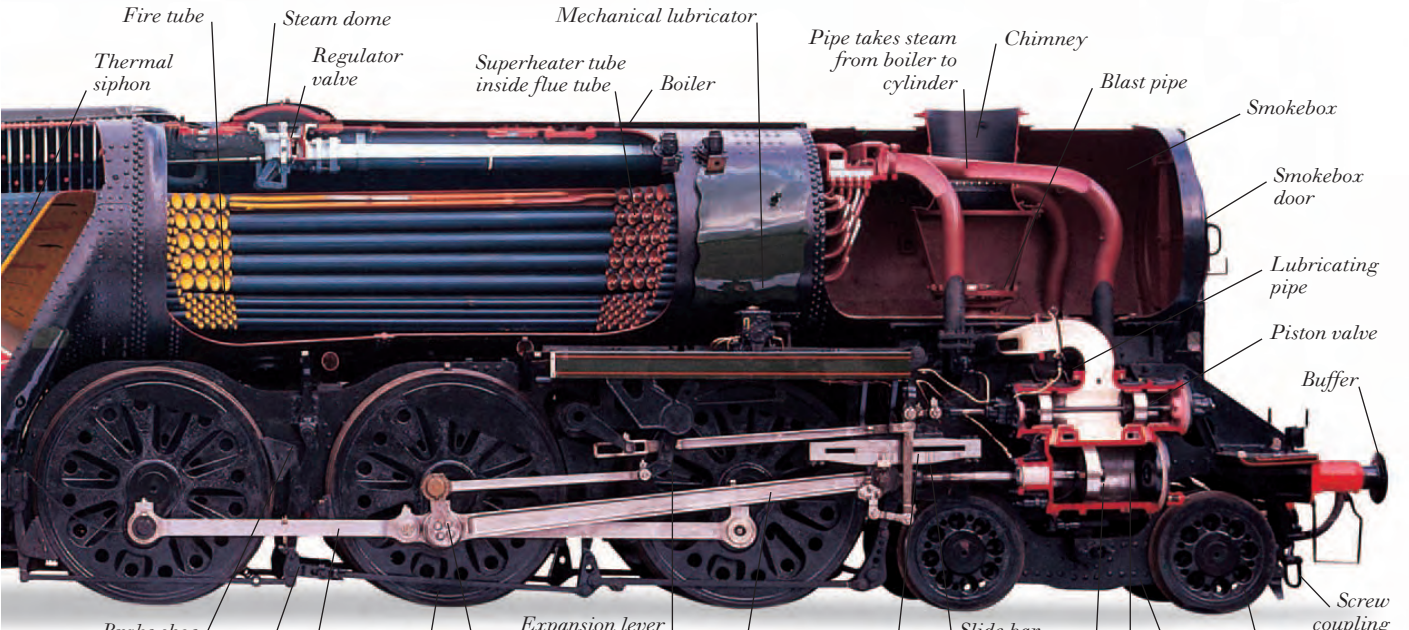


ELLERMAN LINES, 1949 (CUTAWAY VIEW)



TENDER

CAB INTERIOR OF MALLARD EXPRESS STEAM LOCOMOTIVE, 1938

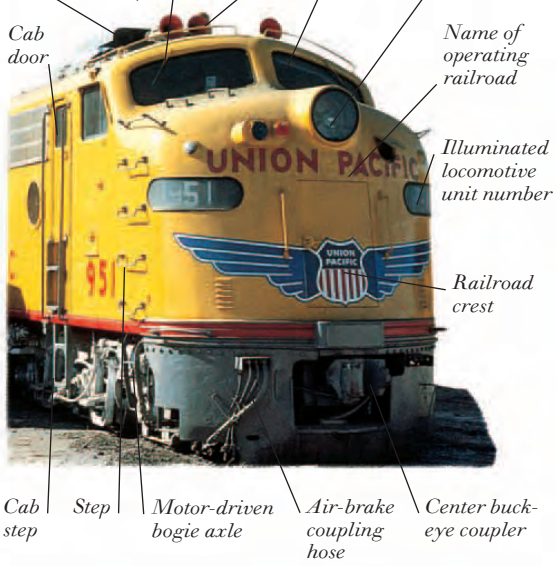


STEAM LOCOMOTIVE

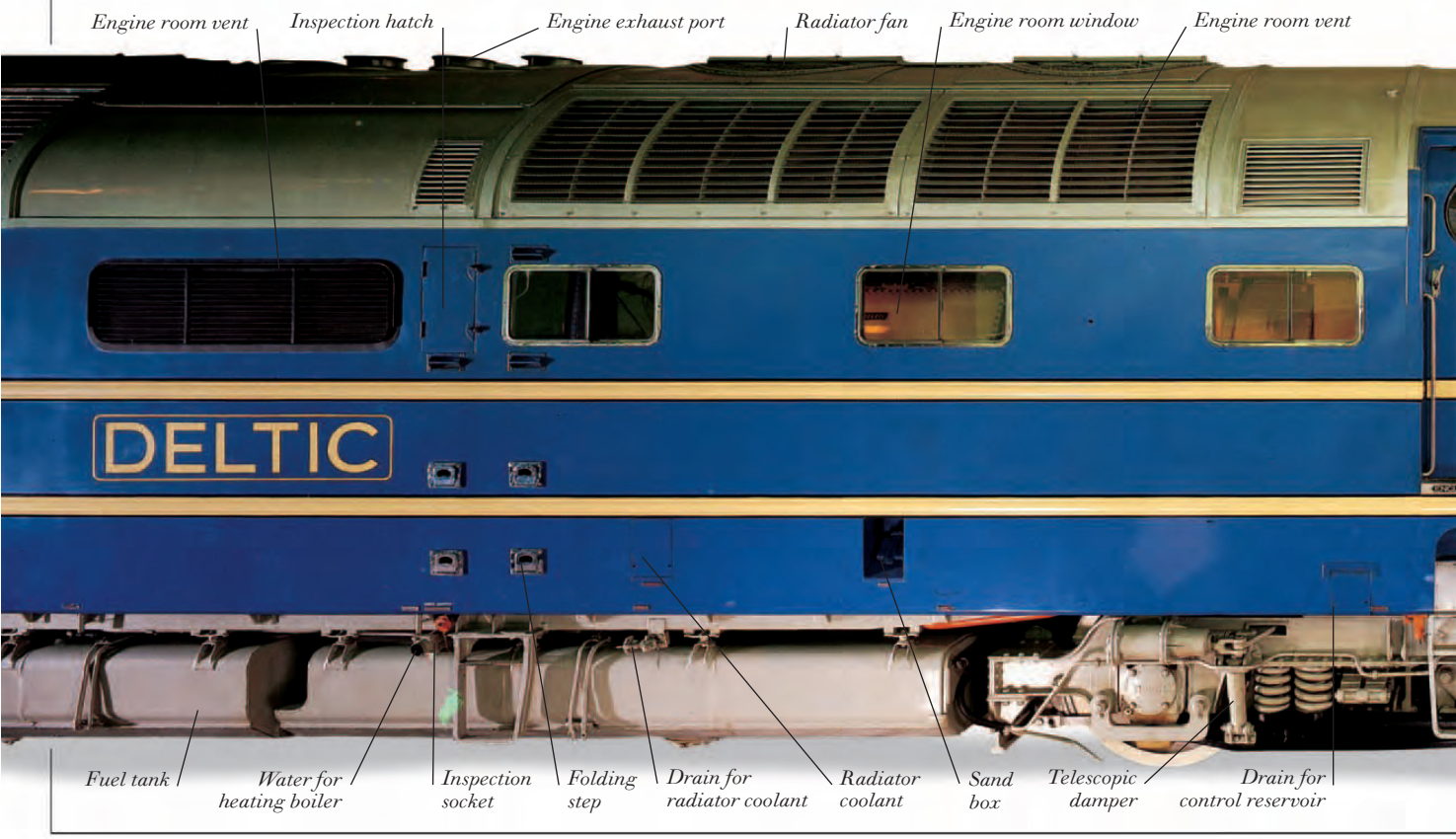
Diesel trains

RUDOLF DIESEL FIRST DEMONSTRATED the diesel engine in Germany in 1898, but it was not until the 1940s that diesel locomotives were successfully established on both passenger and freight services in the US. Early diesel locomotives like the Union Pacific were more expensive to build than steam locomotives, but were more efficient and cheaper to operate, especially where oil was plentiful. One feature of diesel engines is that the power output cannot be coupled directly to the wheels. To convert the mechanical energy produced by diesel engines, a transmission system is needed. Almost all diesel locomotives have electric transmissions, and are known as diesel-electric locomotives. The diesel engine works by drawing air into the cylinders and compressing it to increase its temperature; a small quantity of diesel fuel is then injected into it. The resulting combustion drives the generator (more recently an alternator) to produce electricity, which is fed to electric motors connected to the wheels. Diesel-electric locomotives are essentially electric locomotives that carry their own power plants, and are used worldwide today. The Deltic diesel-electric locomotive, similar to the one shown here, replaced classic express steam locomotives, and ran at speeds up to 100 mph (160 kph).

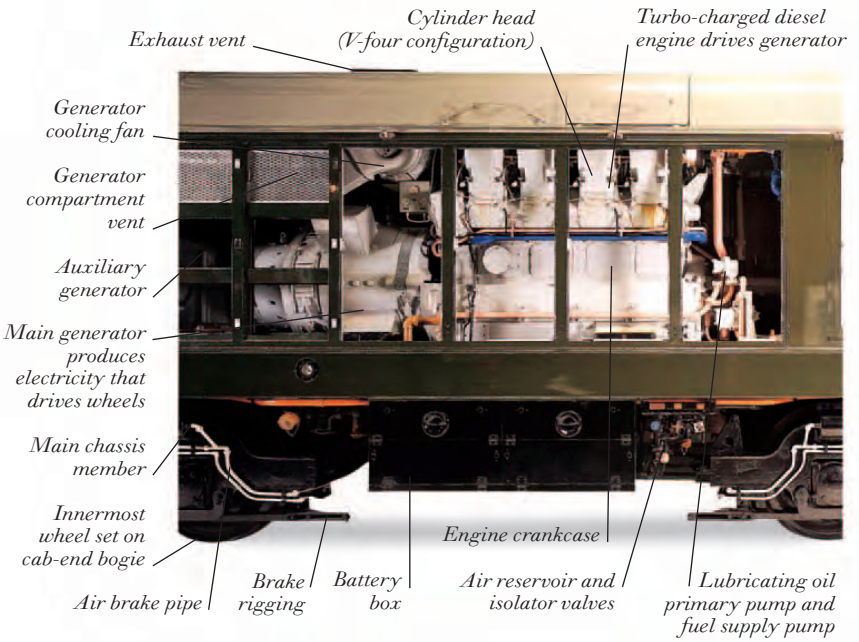
FRONT VIEW OF UNION PACIFIC DIESEL-ELECTRIC LOCOMOTIVE, 1950s

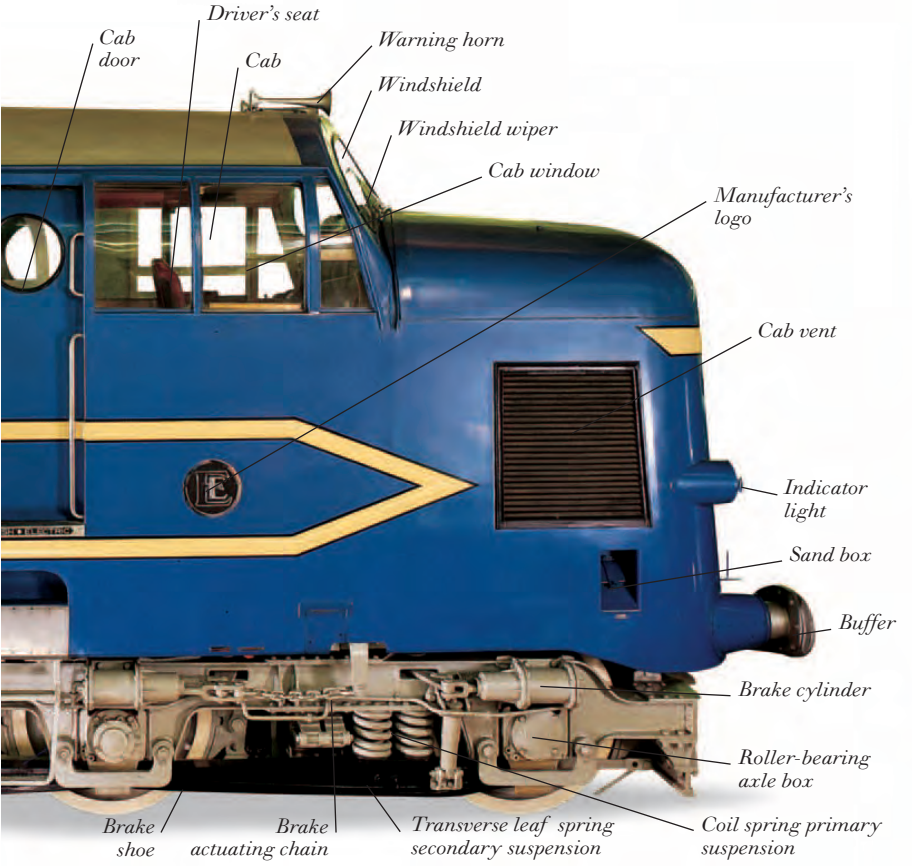


PROTOTYPE DELTIC DIESEL-ELECTRIC LOCOMOTIVE, 1956



DIESEL ENGINE OF BRITISH RAIL CLASS 20 DIESEL-ELECTRIC LOCOMOTIVE





EXAMPLES OF FREIGHT CARS

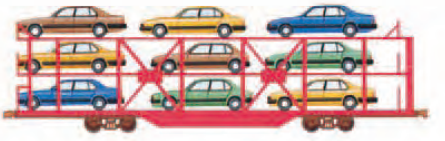
BOX CAR

HOPPER CAR

REFRIGERATOR CAR

LIVESTOCK CAR

FLAT CAR WITH BULKHEADS

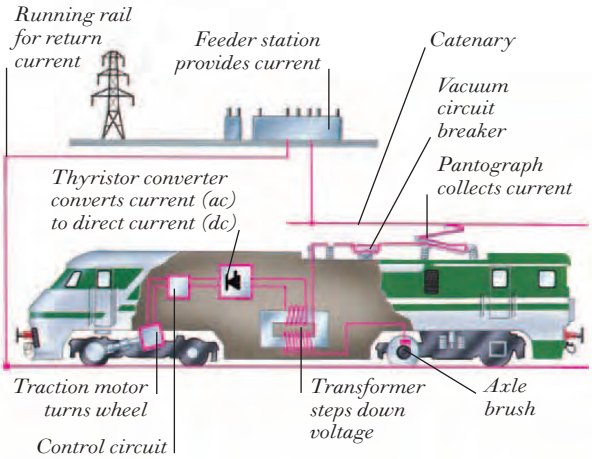


AUTOMOBILE CAR

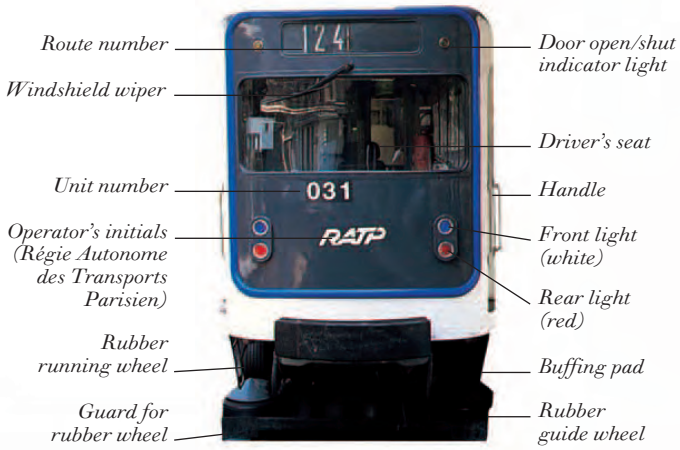
Electric and high-speed trains

THE FIRST ELECTRIC LOCOMOTIVE ran in 1879 in Berlin, Germany. In Europe, electric trains developed as a more efficient alternative to the steam locomotive and diesel-electric power. Like diesels, electric trains employ electric motors to drive the wheels but, unlike diesels, the electricity is generated externally at a power station. Electric current is picked up either from a catenary (overhead cable) via a pantograph, or from a third rail. Since it does not carry its own power-generating equipment, an electric locomotive has a better power-to-weight ratio and greater acceleration than its diesel-electric equivalent. This makes electric trains suitable for urban routes with many stops. They are also faster, quieter, and cause less pollution. The latest electric French TGV (Train à Grande Vitesse) reaches 185 mph (300 kph); other trains, like the London to Paris and Brussels Eurostar, can run at several voltages and operate between different countries. Simpler electric trains perform special duties—the "People Mover" at Gatwick Airport in London runs between terminals.

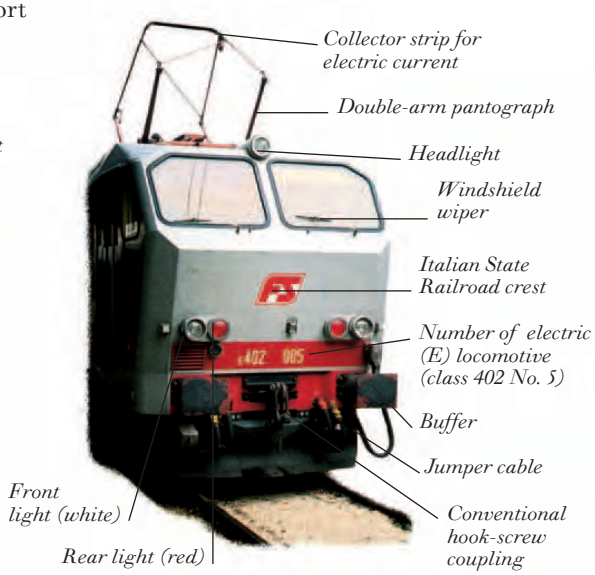
HOW ALTERNATING CURRENT (AC) ELECTRIC TRAINS WORK



FRONT VIEW OF PARIS METRO

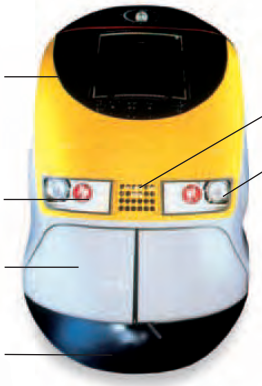


FRONT VIEW OF ITALIAN STATE RAILROADS CLASS 402 ELECTRIC LOCOMOTIVE

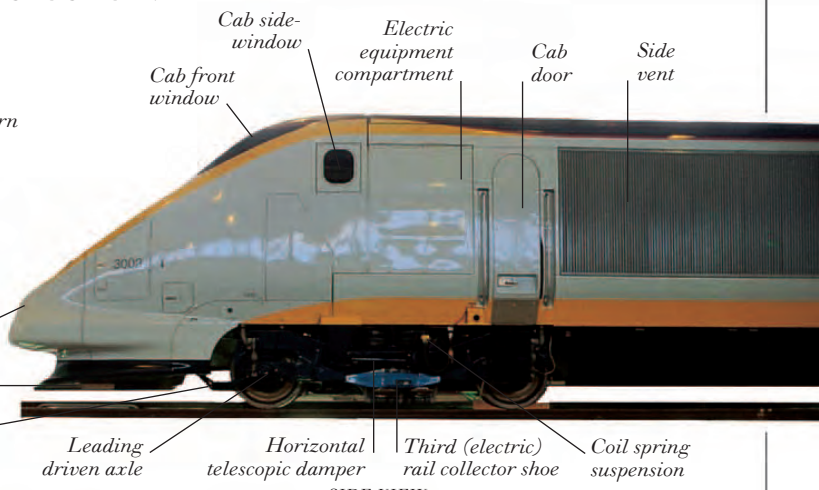


SIDE VIEW OF SHANGHAI MAGLEV TRAIN

EUROSTAR MULTIVOLTAGE ELECTRIC TRAIN



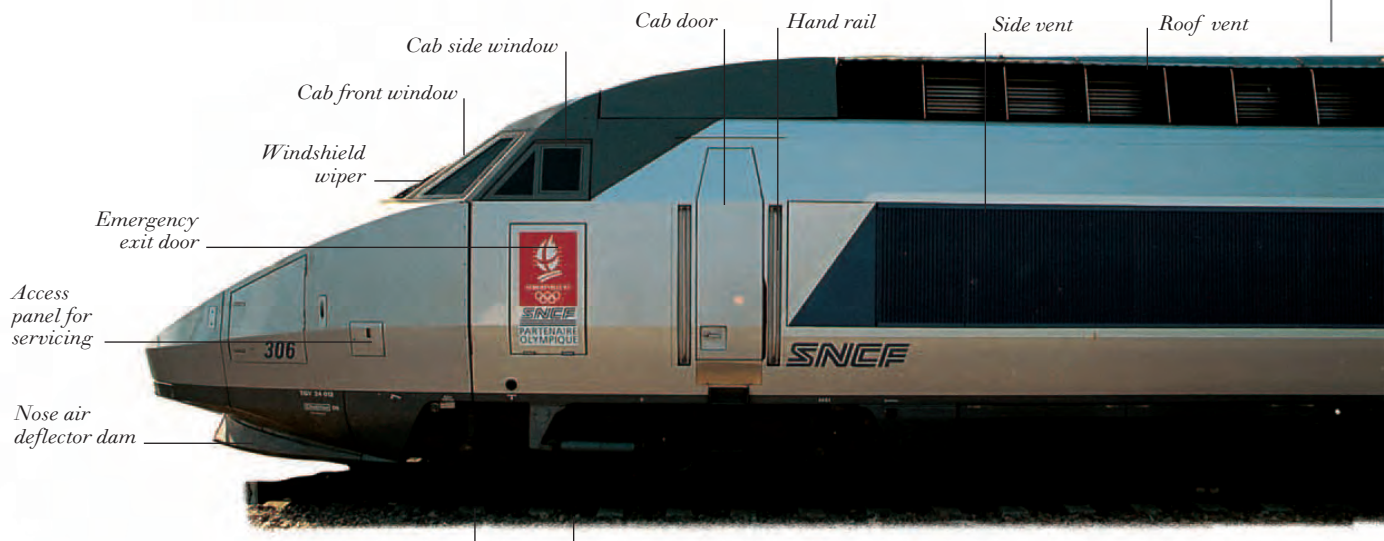
FRONT VIEW



SIDE VIEW

TGV ELECTRIC HIGH-SPEED TRAIN

INTERIOR OF TGV

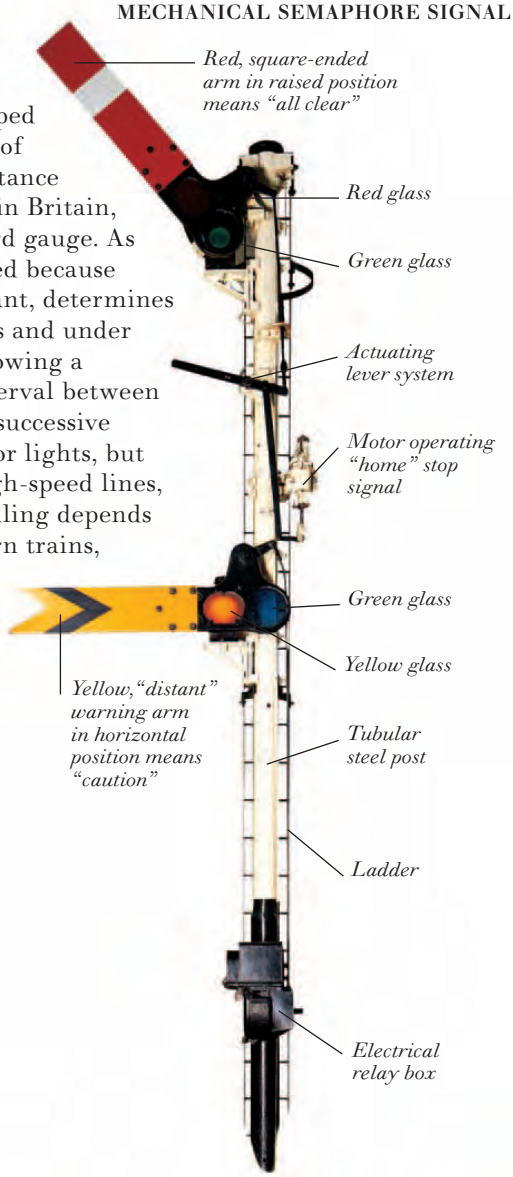


SIDE VIEW OF TGV

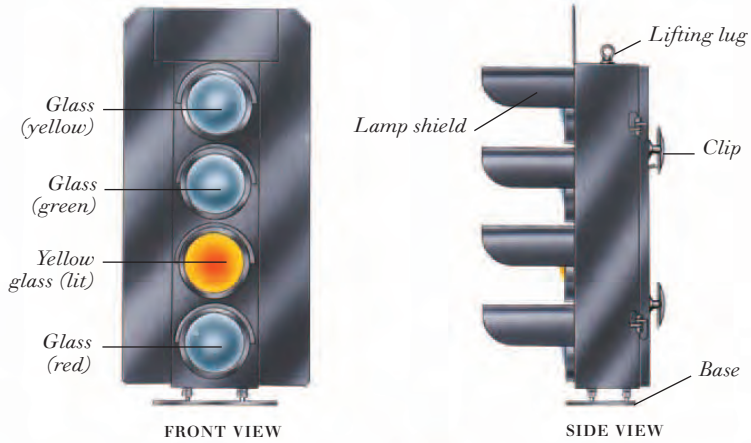
Train equipment

MODERN RAILROAD TRACK consists of two parallel steel rails clipped on to a support called a railroad tie. Railroad ties are usually made of reinforced concrete, although wood and steel are still used. The distance between the inside edges of the rails is the track gauge. It evolved in Britain, which uses a gauge of 4 ft 8½ in (1,435 mm), known as the standard gauge. As engineering grew more sophisticated, narrower gauges were adopted because they cost less to build. The loading gauge, which is equally important, determines the size of the largest loaded vehicle that may pass through tunnels and under bridges with adequate clearance. Safe train operation relies on following a signaling system. At first, signaling was based on a simple time interval between trains, but it now depends on maintaining a safe distance between successive trains traveling in the same direction. Most modern signals are color lights, but older mechanical semaphore signals are still used. On the latest high-speed lines, train drivers receive control instructions by electronic means. Signaling depends on reliable control of the train by effective braking. For fast, modern trains, which have considerable momentum, it is essential that each vehicle in the train can be braked by the driver or by a train control system, such as Automatic Train Protection (ATP). Braking is achieved by the brake shoe acting on the wheel rim (rim brakes), by disc brakes, or, increasingly, by electrical braking.

MECHANICAL SEMAPHORE SIGNAL

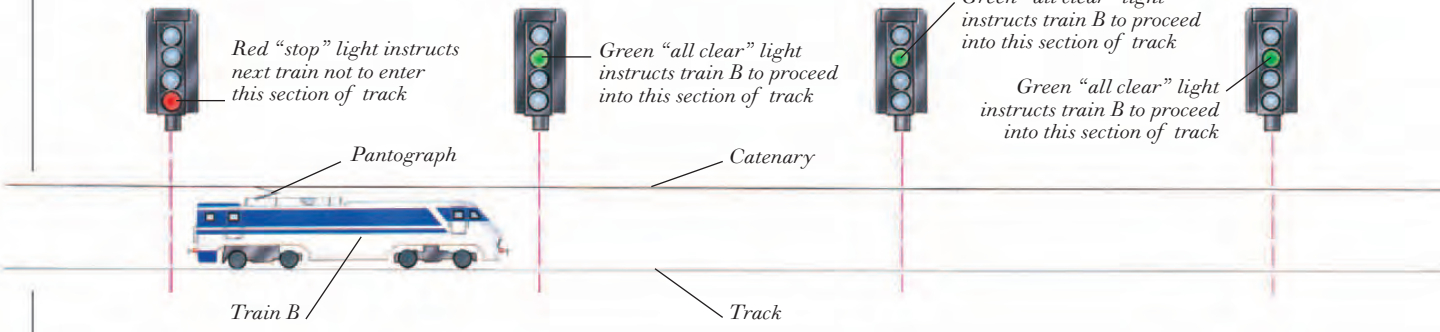


FOUR-ASPECT COLOR LIGHT SIGNAL

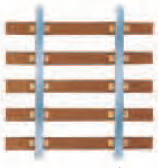


FRONT VIEW SIDE VIEW

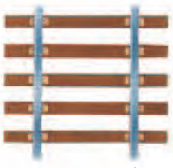
HOW A MODERN MAIN-LINE SIGNALING SYSTEM WORKS



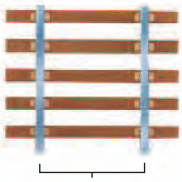
EXAMPLES OF INTERNATIONAL TRACK GAUGES



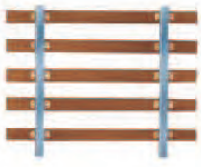
3 ft 3½ in (1,000 mm) East Africa, India, Malaysia, Chile, and Argentina



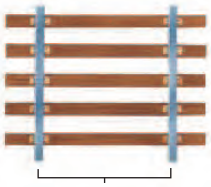
3 ft 6 in (1,067 mm) Japan, Australia, Sudan, West Africa, South Africa, and New Zealand



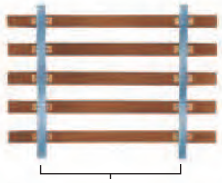
4 ft 8½ in (1,435 mm) US, Canada, China, Egypt, Turkey, Iran, Japan, Peru, Britain, Europe, Australia, Brazil, and Mexico



5 ft 0 in (1,524 mm) Russia, Spain, Portugal, and Finland



5 ft 3 in (1,600 mm) Ireland, Australia, and Brazil



5 ft 6 in (1,676 mm) India, Pakistan, and Argentina

EXAMPLES OF INTERNATIONAL LOADING GAUGES

Britain: 9 ft 0 in (2.75 m) × 12 ft 11 in (3.95 m)

Europe: 10 ft 2 in (3.1 m) × 14 ft 9 in (4.5 m)

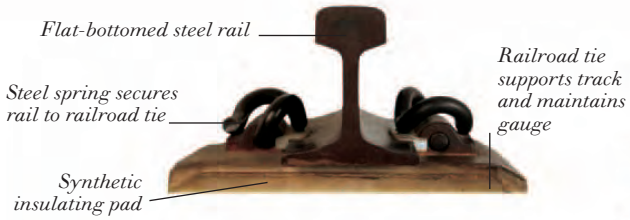
US: 10 ft 10 in (3.3 m) × 16 ft 2 in (4.9 m)

Russia: 11 ft 2 in (3.4 m) × 17 ft 4 in (5.3 m)

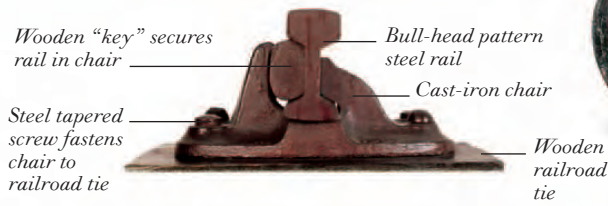
4 ft 8½ in (1,435 mm) Standard track gauge

5 ft 0 in (1,524 mm) Track gauge of Russia, with largest loading gauge

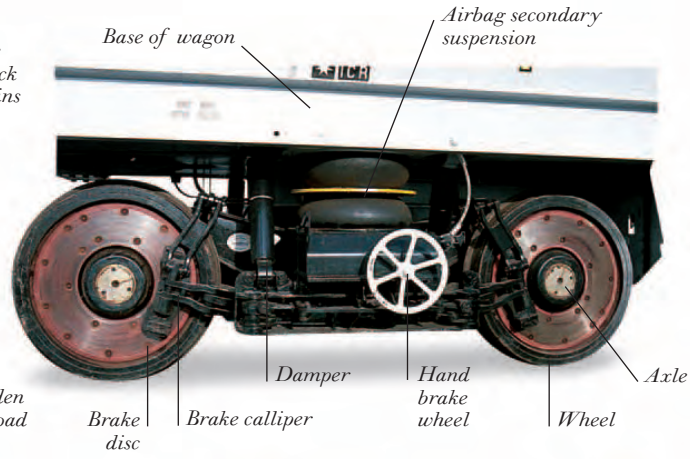
FLAT-BOTTOMED RAIL

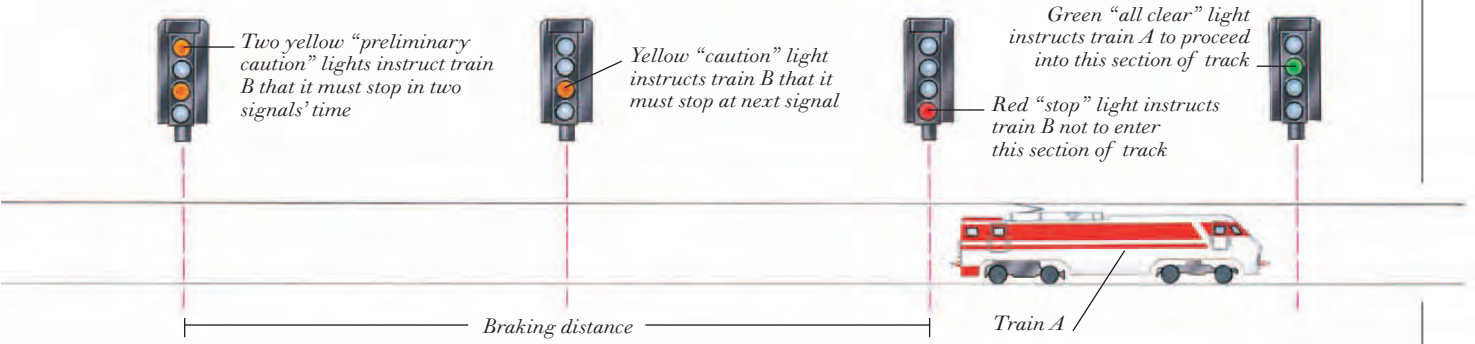


BULL-HEAD RAIL



DISC BRAKES ON MODERN WAGON BOGIE



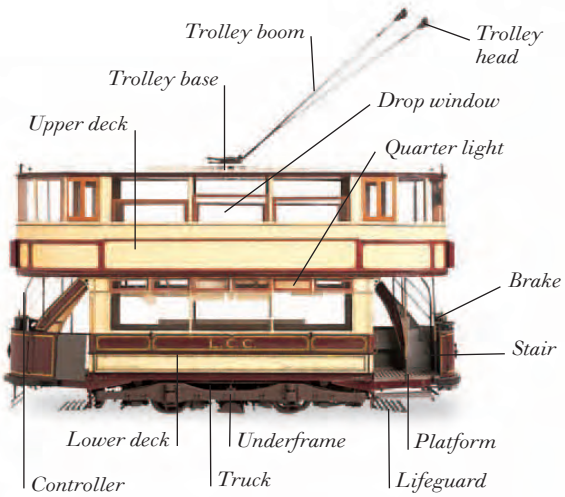


Trolleys and buses

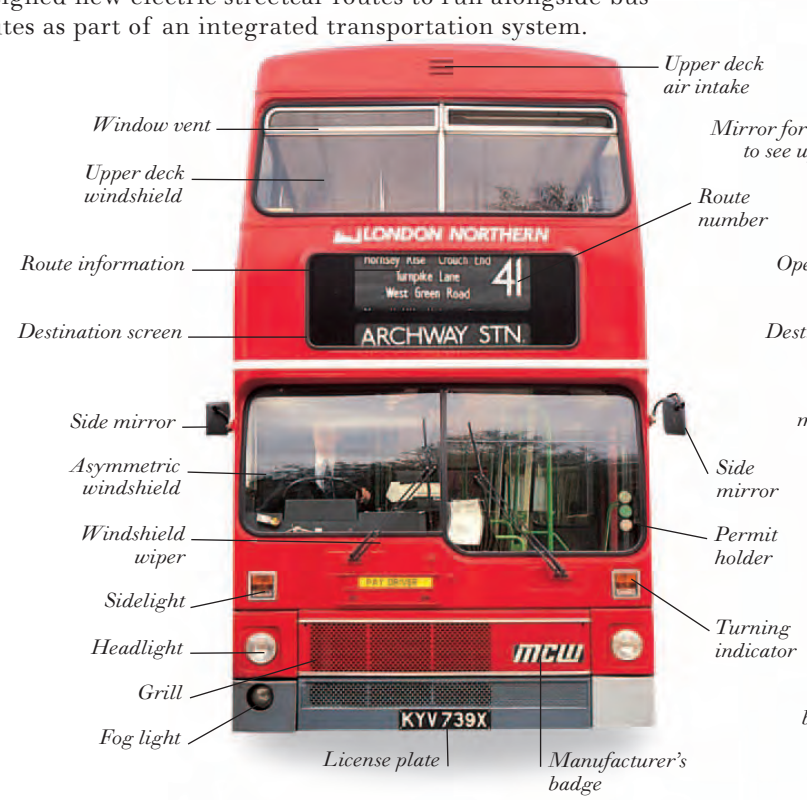
METROLINK TROLLEY, MANCHESTER, UK

As city populations exploded in the 1800s, there was an urgent need for mass transportation. Trolleys were an early solution. The first trolleys, like buses, were horse-drawn, but in 1881, electric streetcars appeared in Berlin, Germany. Electric streetcars soon became widespread throughout Europe and North America. Trolleys run on rails along a fixed route, using electric motors that receive power from overhead cables. As road networks developed, motorized buses offered a flexible alternative to trolleys. By the 1930s, they had replaced trolley systems in many cities. City buses typically have doors at both front and rear to make loading and unloading easier. Double-decker designs are popular, occupying the same amount of street space as single-decker buses but able to transport twice the number of people. Buses are also commonly used for inter-city travel and touring. Tour buses have reclining seats, large windows, luggage space, and toilets. Recently, as city traffic has become increasingly congested, many city planners have designed new electric streetcar routes to run alongside bus routes as part of an integrated transportation system.

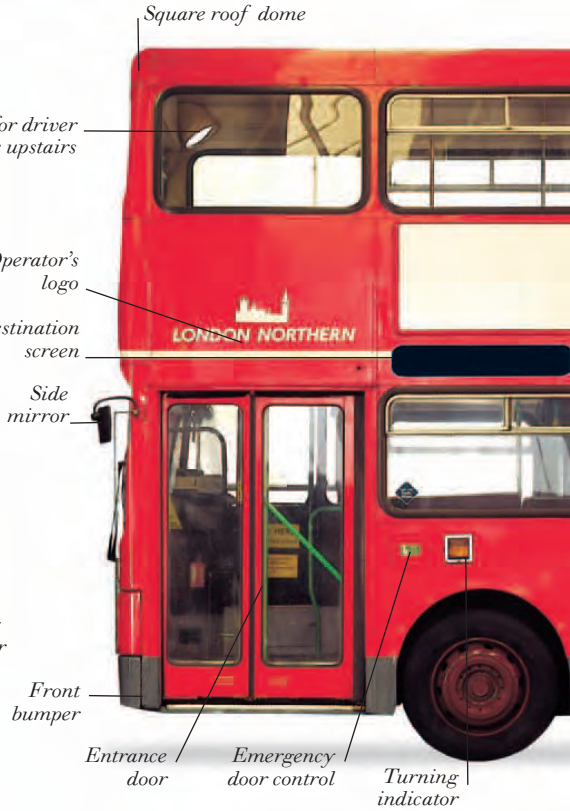
TROLLEY, c.1900



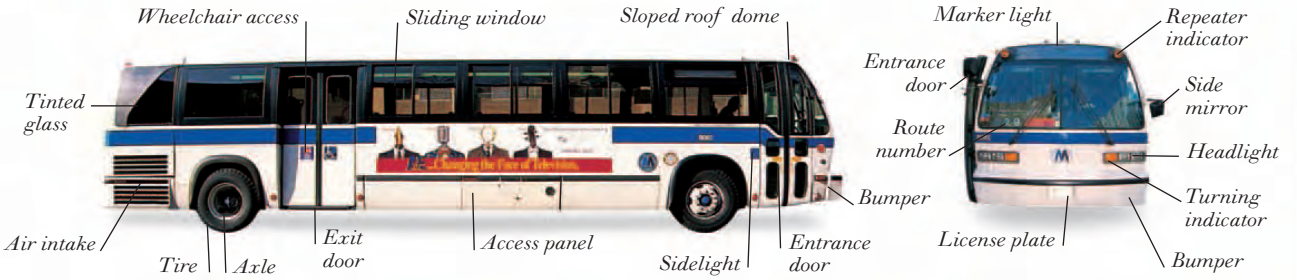
MCW METROBUS, LONDON, UK



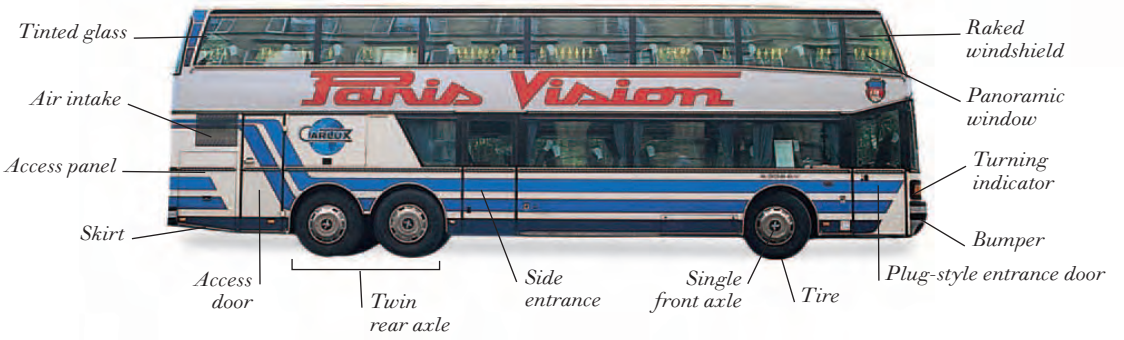
FRONT VIEW

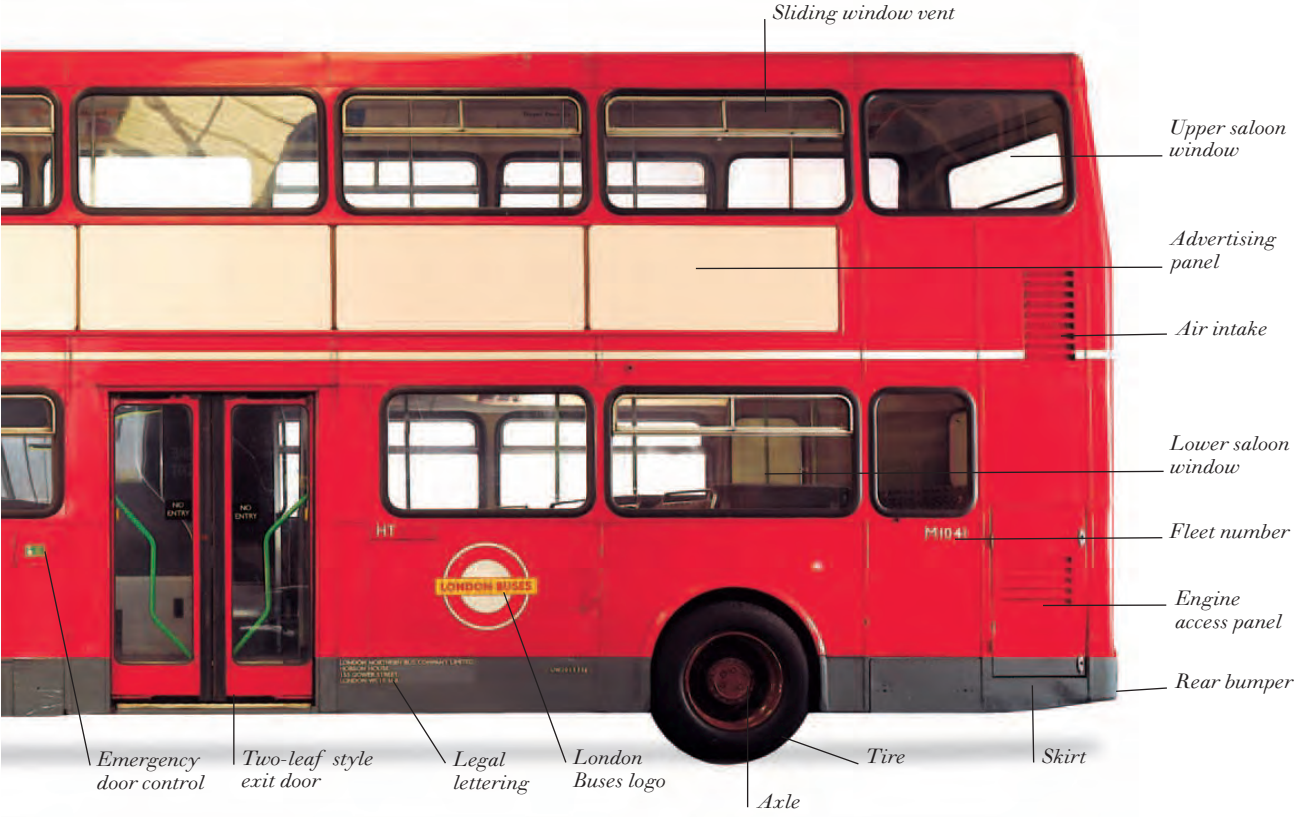


SINGLE-DECKER BUS, NEW YORK CITY



DOUBLE-DECKER TOUR BUS, PARIS, FRANCE

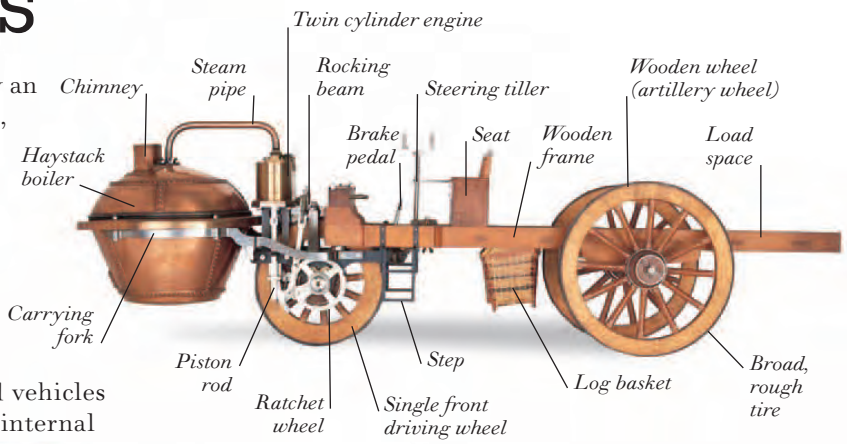




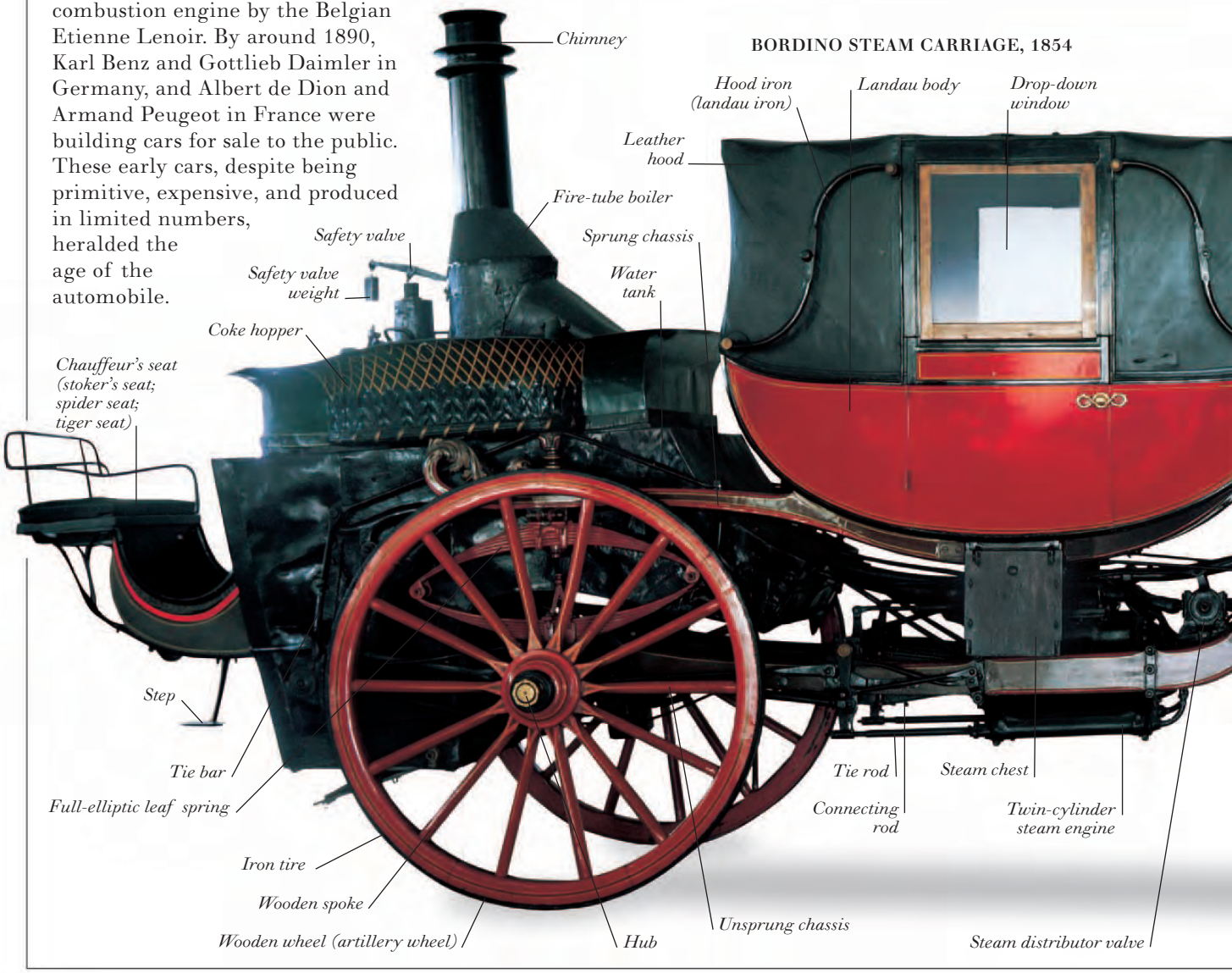
The first cars

THE EARLIEST ROAD VEHICLE powered by an engine, the Cugnot steam traction engine, was built in 1770. More practical steam carriages, such as the Bordino, were available in the early 19th century, but they were heavy and cumbersome. Restrictive laws and the introduction of railroads, faster and able to carry more passengers, saw the decline of "cars" powered by steam. It was not until 1860 that the first practical power unit for road vehicles was developed, with the invention of the internal combustion engine by the Belgian Etienne Lenoir. By around 1890, Karl Benz and Gottlieb Daimler in Germany, and Albert de Dion and Armand Peugeot in France were building cars for sale to the public. These early cars, despite being primitive, expensive, and produced in limited numbers, heralded the age of the automobile.

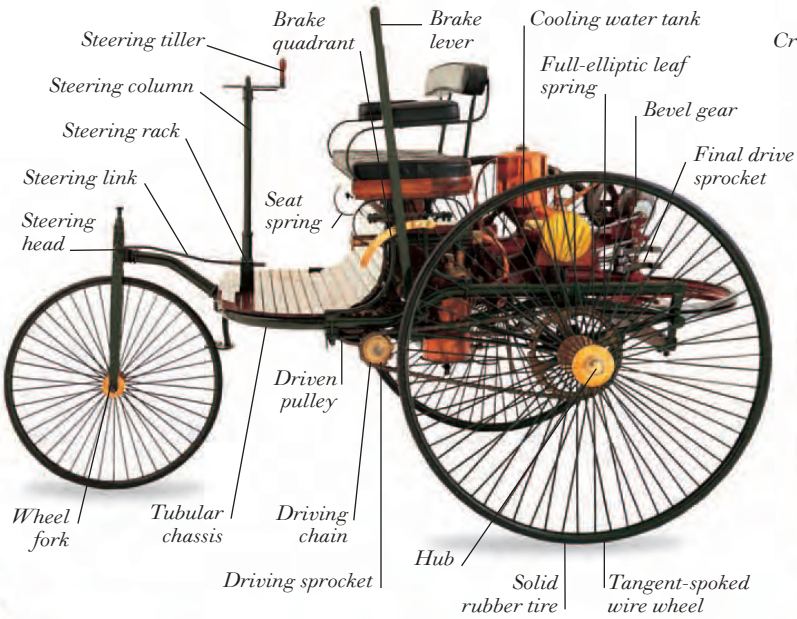
STEAM-POWERED CUGNOT FARDIER, 1770



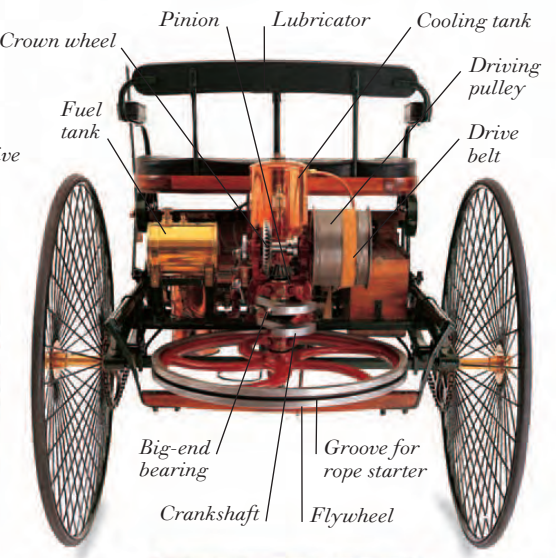
BORDINO STEAM CARRIAGE, 1854



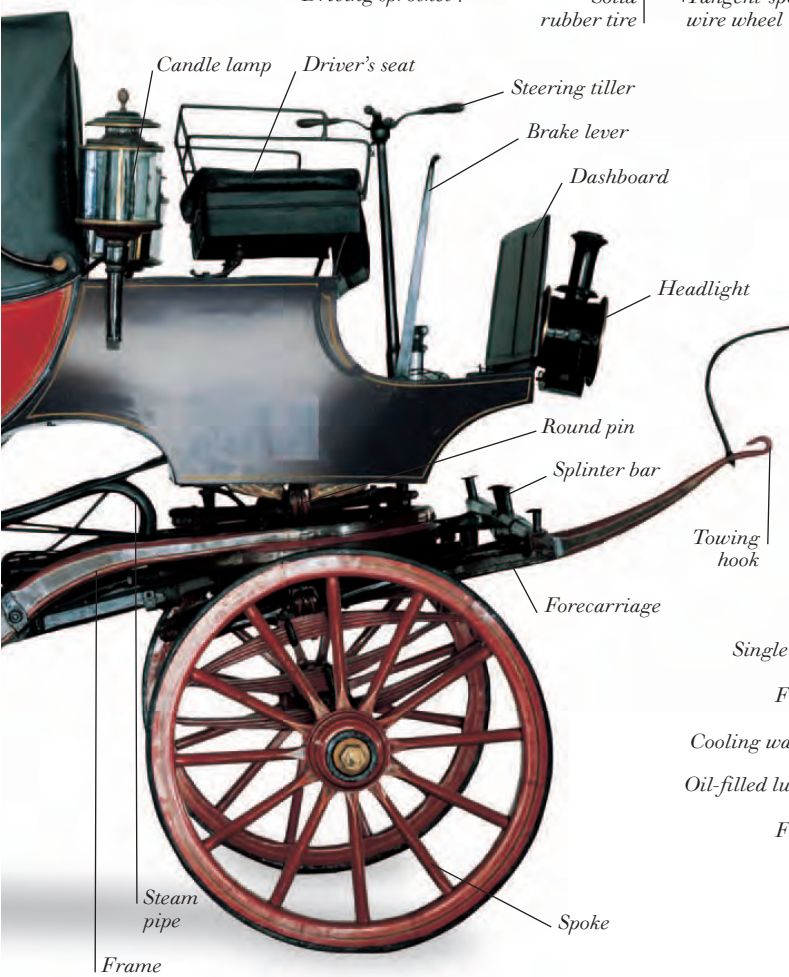
SIDE VIEW OF GAS-DRIVEN BENZ MOTORWAGEN, 1886



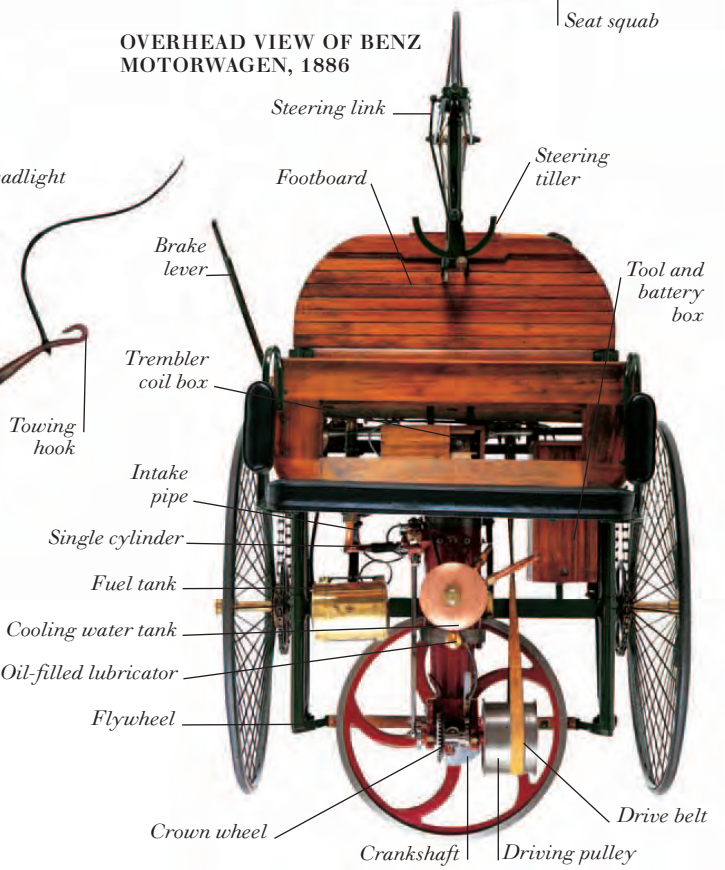
REAR VIEW OF BENZ MOTORWAGEN, 1886



Seat squab



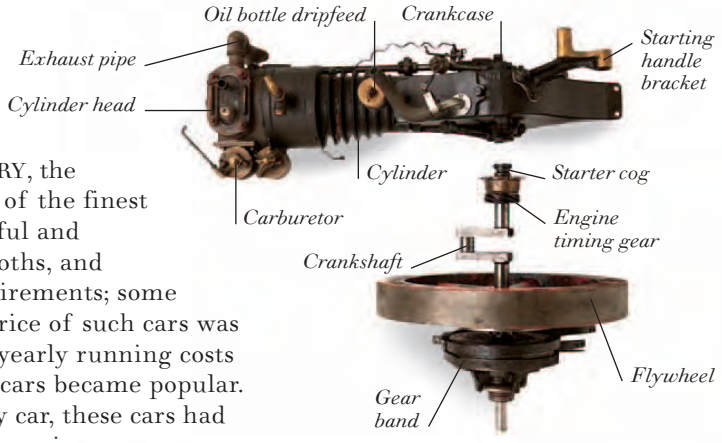
OVERHEAD VIEW OF BENZ MOTORWAGEN, 1886



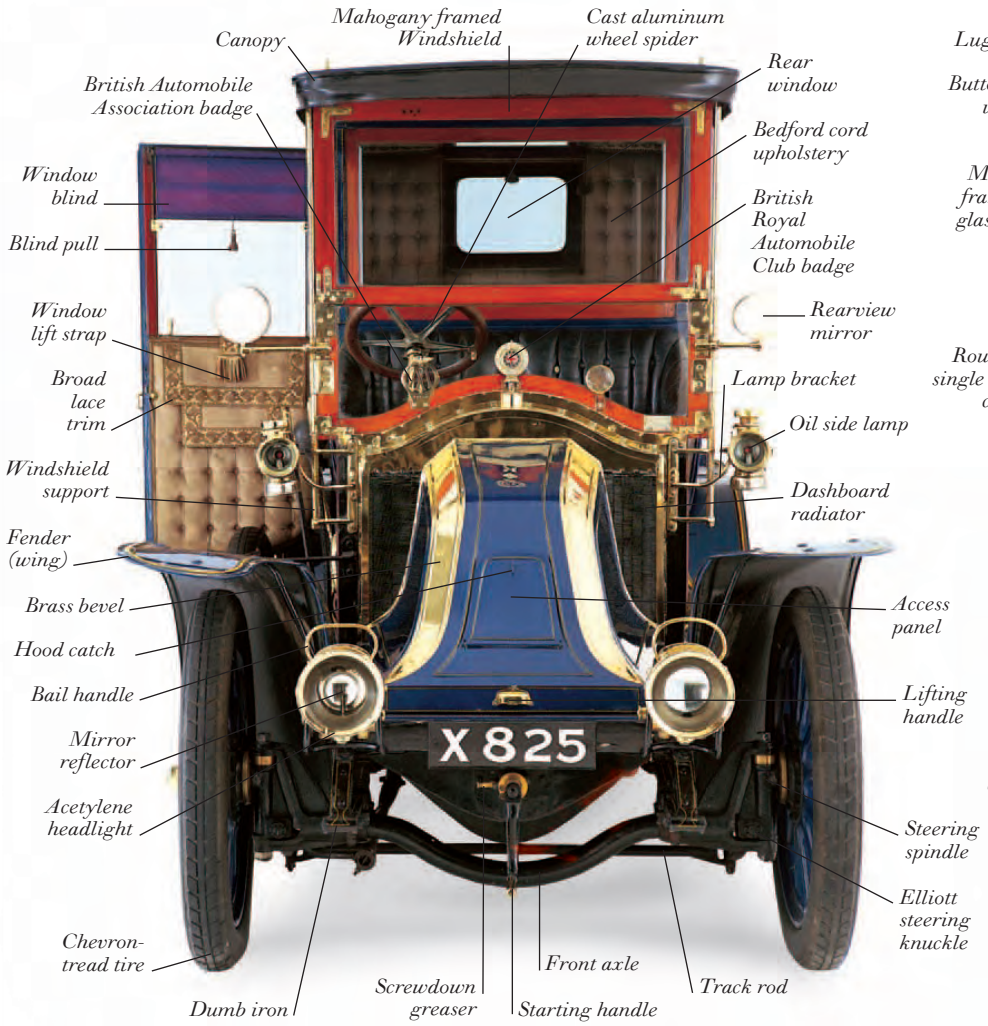
Elegance and utility

DURING THE FIRST DECADE OF THE 20TH CENTURY, the motorist who could afford it had a choice of some of the finest cars ever made. These handbuilt cars were powerful and luxurious, using the finest woods, leathers, and cloths, and bodywork made to the customer's individual requirements; some had six-cylinder engines as big as 15 liters. The price of such cars was several times that of an average house, and their yearly running costs were also very high. As a result, basic, utilitarian cars became popular. Costing perhaps one-tenth of the price of a luxury car, these cars had very little trim and often had only single-cylinder engines.

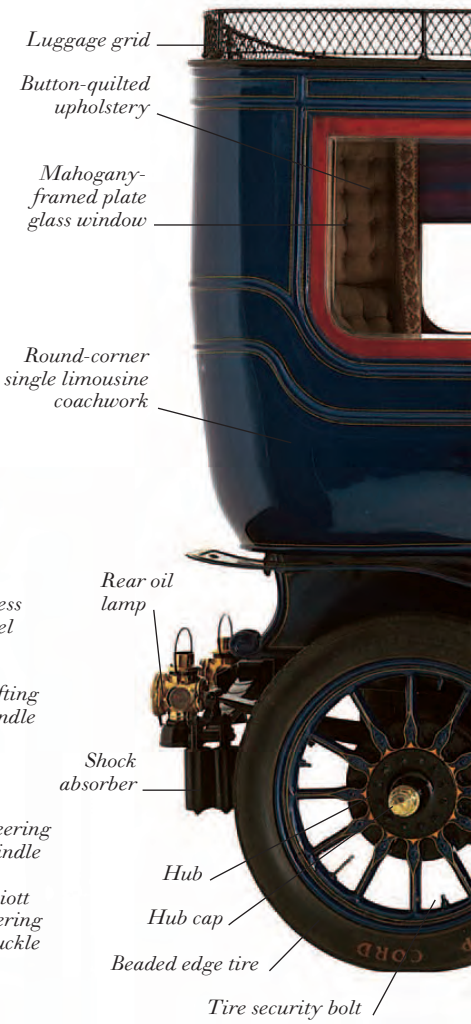
1904 OLDSMOBILE SINGLE-CYLINDER ENGINE



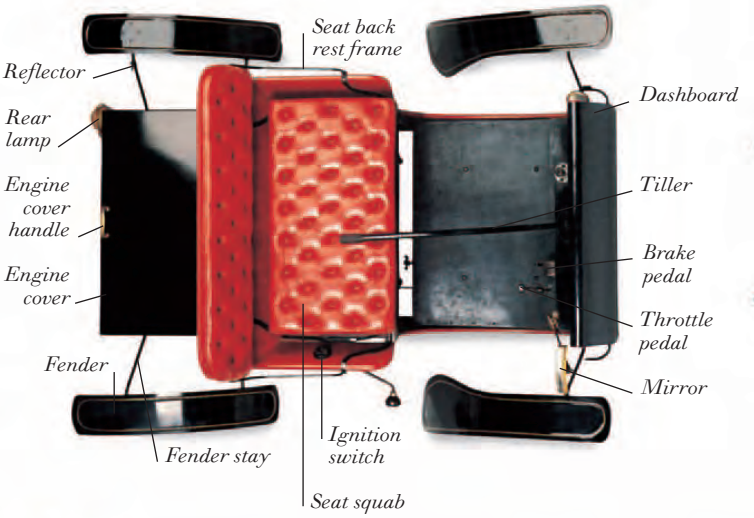
FRONT VIEW OF 1906 RENAULT



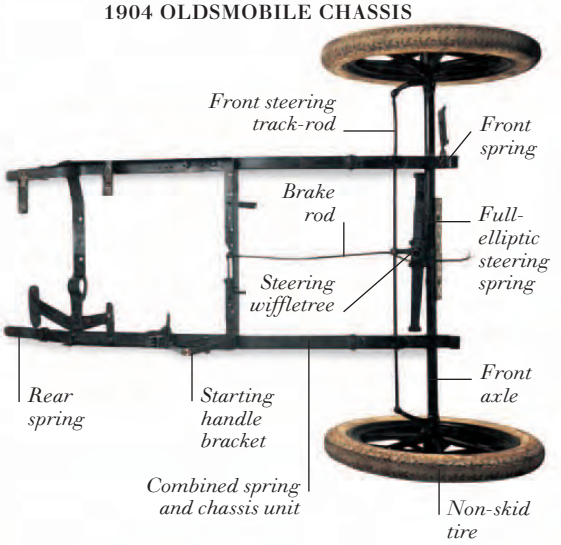
SIDE VIEW OF 1906 RENAULT

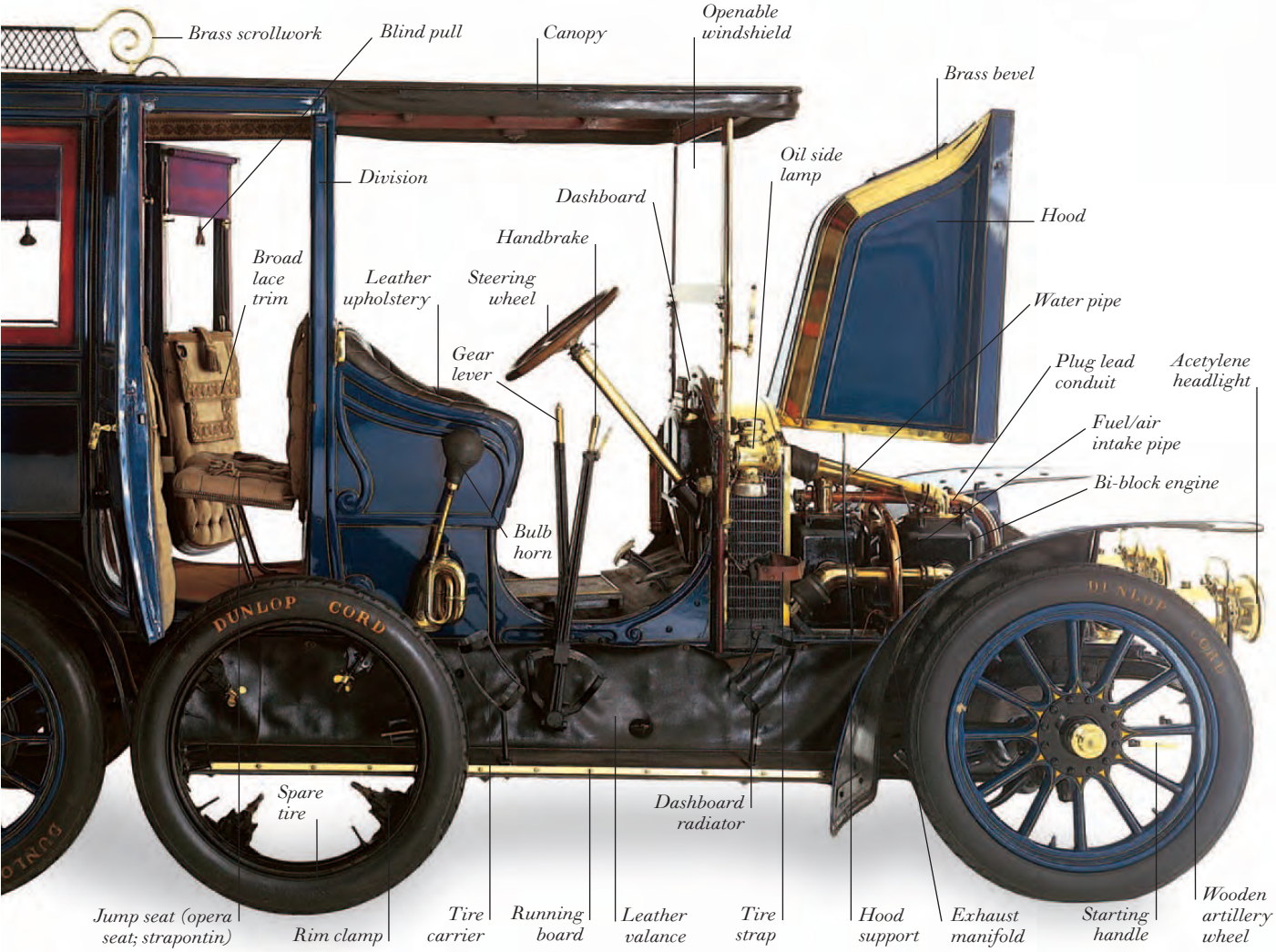


1904 OLDSMOBILE TRIM AND BODYWORK



1904 OLDSMOBILE CHASSIS

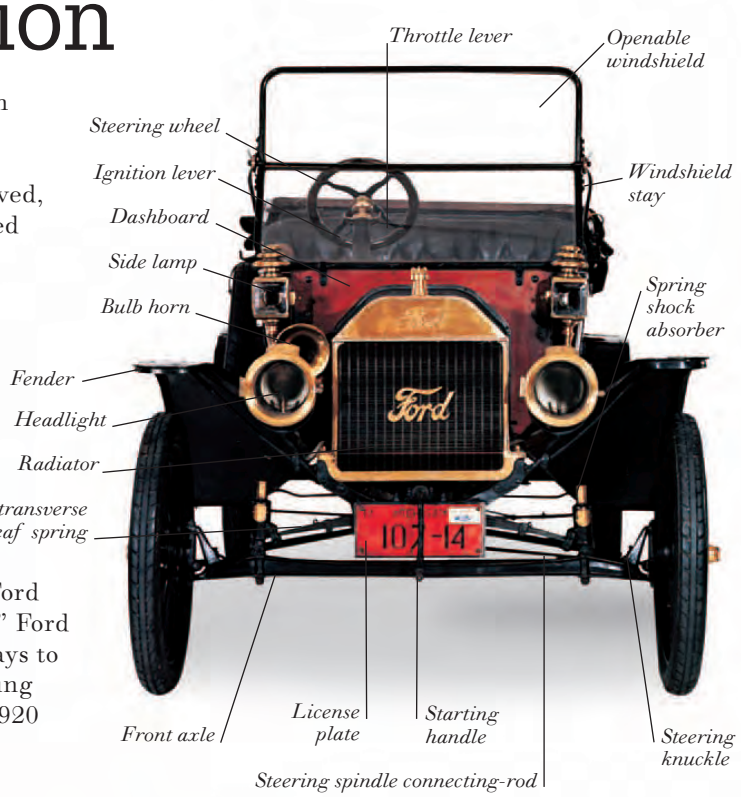




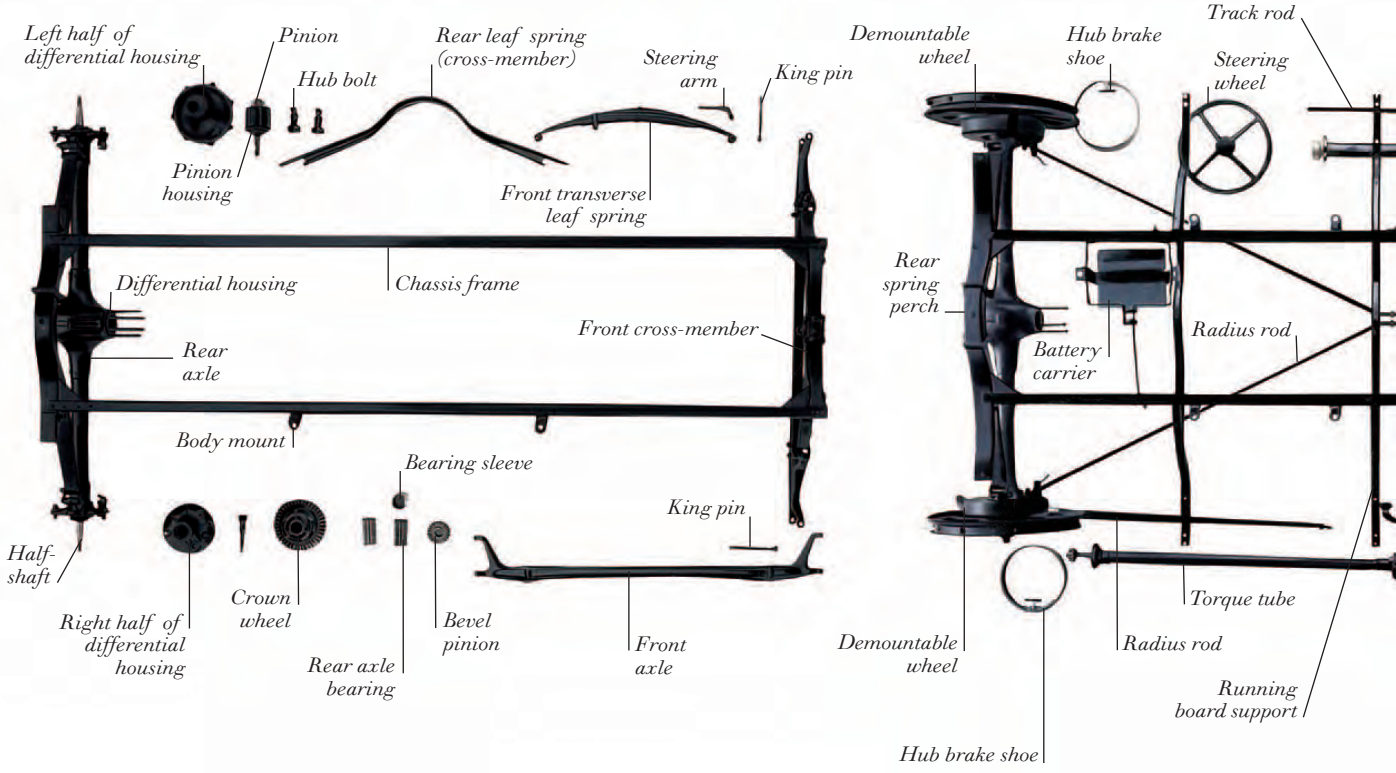
Mass-production

THE FIRST CARS WERE HAND-ASSEMBLED from individually built parts, a time-consuming procedure that required skilled mechanics and made cars very expensive. This problem was solved, in America, by a Detroit car manufacturer named Henry Ford; he introduced mass-production by using standardized parts, and later combined these with a moving production line. The work was brought to the workers, each of whom performed one simple task in the construction process as the chassis moved along the line. The first mass-produced car, the Ford Model T, was launched in 1908 and was available in a limited range of body styles and colors. However, when the production line was introduced in 1914, the color range was cut back; the Model T became available, as Henry Ford said, in "any color you like, so long as it's black." Ford cut the production time for a car from several days to about 12 hours, and eventually to minutes, making cars much cheaper than before. As a result, by 1920 half the cars in the world were Model T Fords.

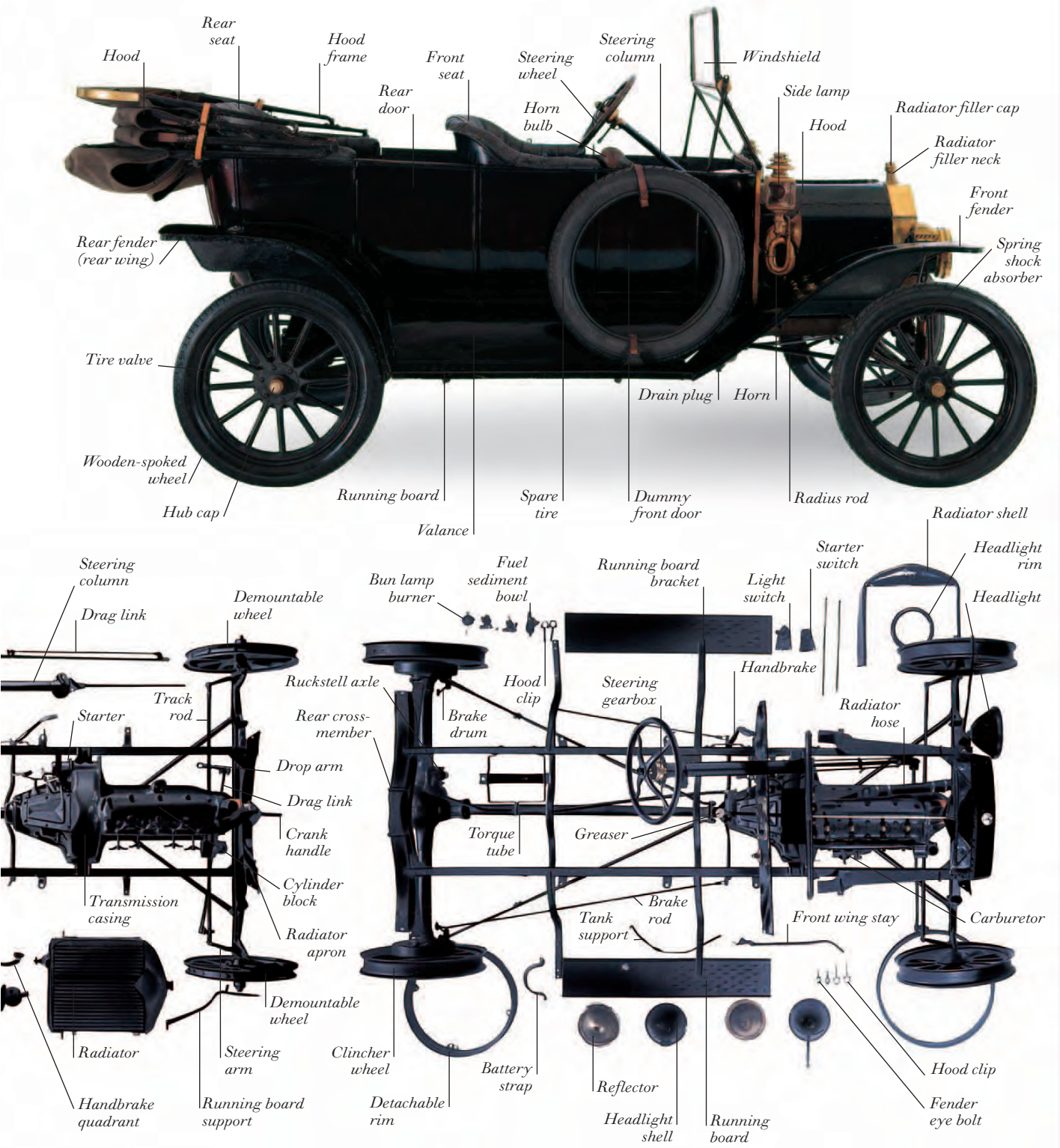
FRONT VIEW OF 1913 FORD MODEL T



STAGES OF FORD MODEL T PRODUCTION



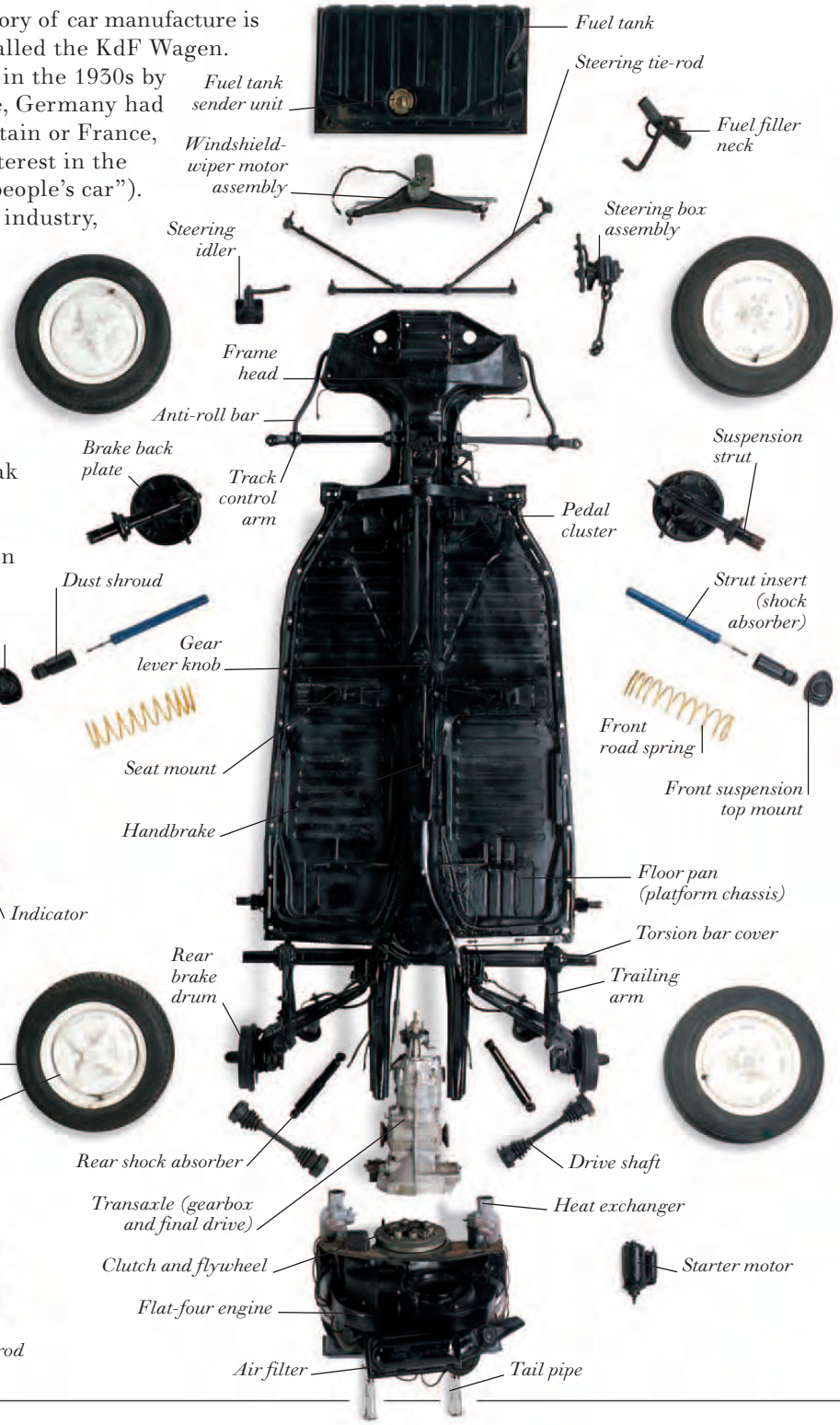
SIDE VIEW OF 1913 FORD MODEL T



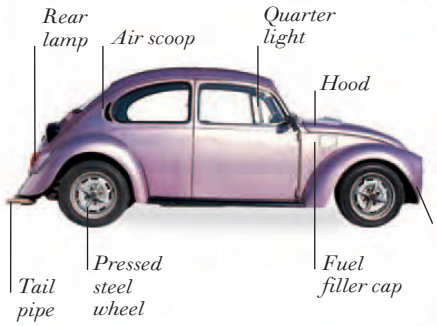
The "people's car"

THE MOST POPULAR CAR in the history of car manufacture is the Volkswagen Beetle, originally called the KdF Wagen. The car was developed in Germany in the 1930s by Dr. Ferdinand Porsche. At that time, Germany had only half the number of cars of Britain or France, and Adolf Hitler took a personal interest in the development of the Volkswagen ("people's car"). The intention was to provide a new industry, new jobs, and a car so cheap that anyone with a job could afford it. Dr. Porsche designed a car that was cheap to build and run; its rear-mounted, air-cooled engine cut down the number of parts needed and also reduced weight. However, few civilians managed to obtain the Beetle before the outbreak of World War II in 1939. After the war, the Beetle proved so popular that eventually more than 20 million were sold.

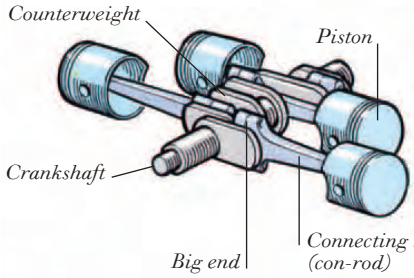
WORKING PARTS OF VOLKSWAGEN BEETLE



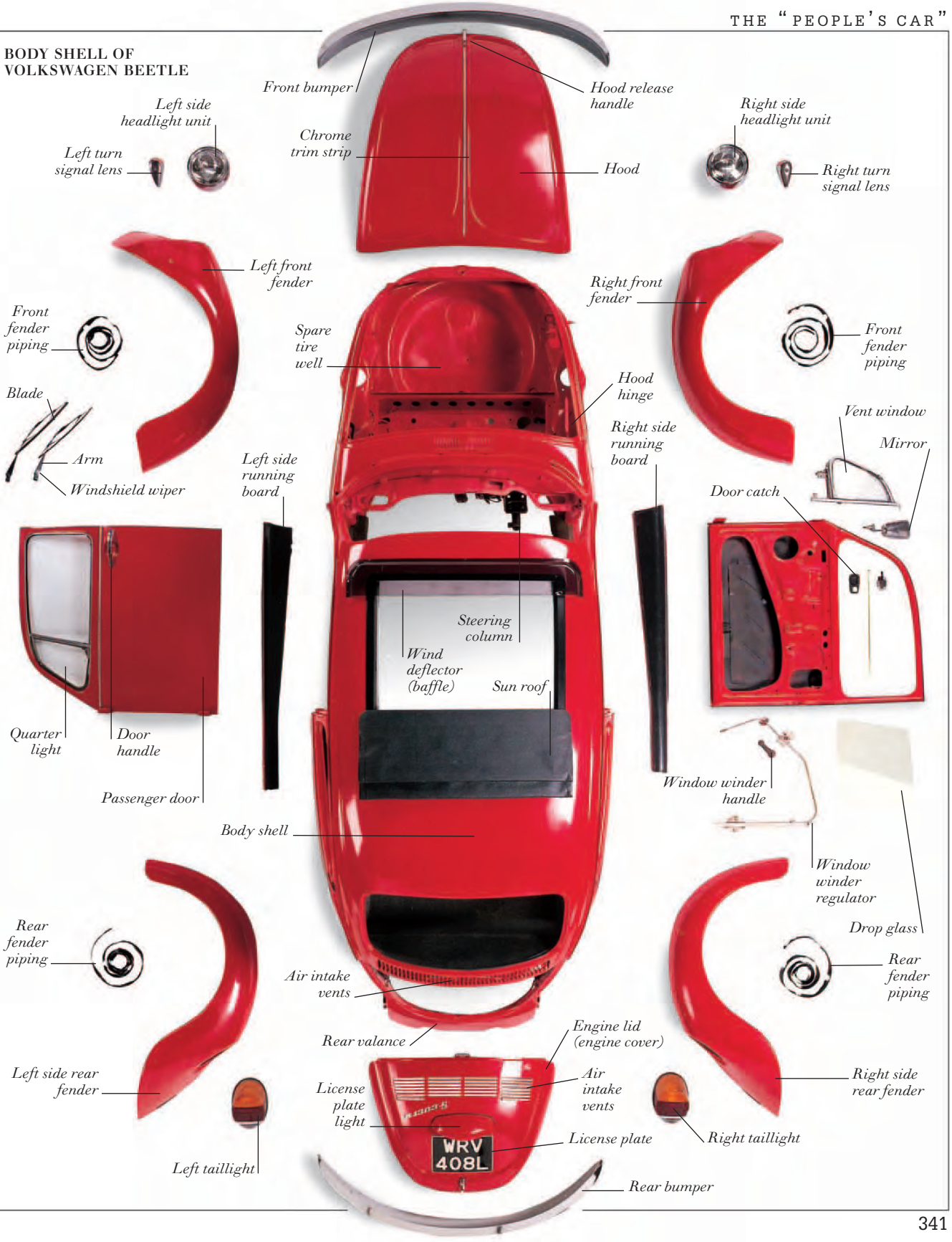
CUSTOMIZED VOLKSWAGEN BEETLE



FLAT-FOUR CYLINDER ARRANGEMENT



BODY SHELL OF VOLKSWAGEN BEETLE

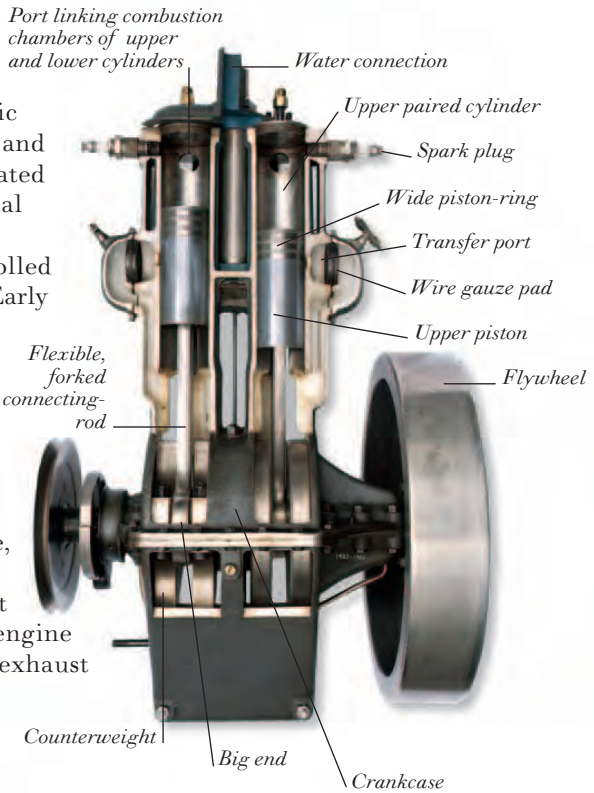


Early engines

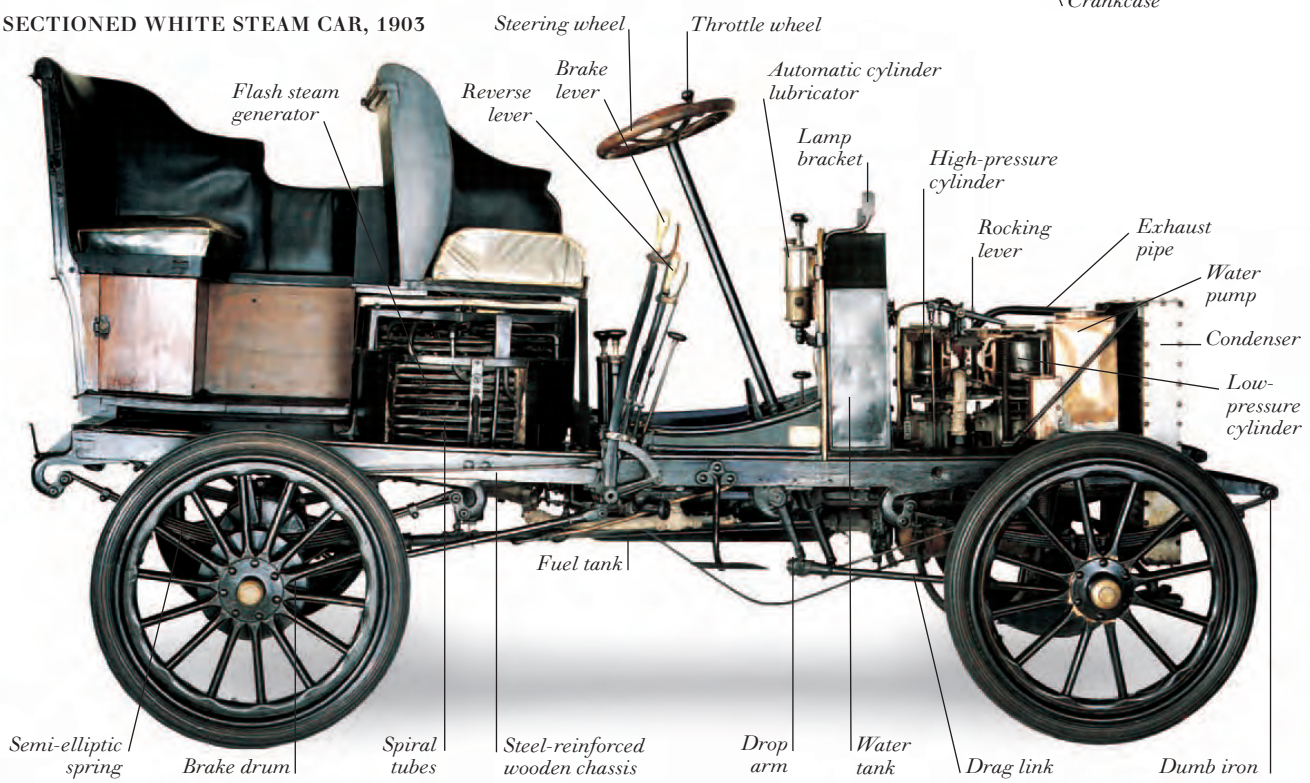
STEAM AND ELECTRICITY were used to power cars until early this century, but neither power source was ideal. Electric cars had to stop frequently to recharge their heavy batteries, and steam cars gave smooth power delivery but were too complicated for the average driver to use. A rival power source, the internal combustion engine, was invented in 1860 by Etienne Lenoir (see pp. 334-335). This engine converted the force of a controlled explosion into rotary motion, to turn the wheels of a vehicle. Early variations on this basic model included sleeve valves, separately cast cylinders, and the two-stroke combustion cycle. Today, many internal combustion engines, including the Wankel rotary and diesels (see pp. 346-347), use the four-stroke cycle, first demonstrated by Nikolaus Otto in 1876. The Otto cycle, often described as "suck, squeeze, bang, blow," has proved the best method of ensuring that the engine turns over smoothly and that exhaust emissions are controllable.

BERSEY ELECTRIC CAB, 1896

TROJAN TWO-STROKE ENGINE, 1927

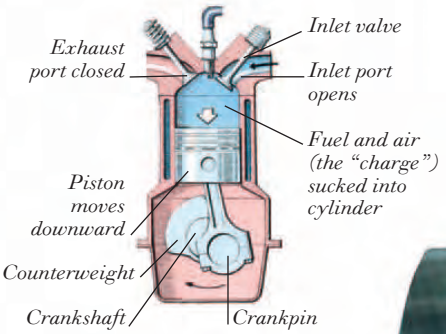


SECTIONED WHITE STEAM CAR, 1903

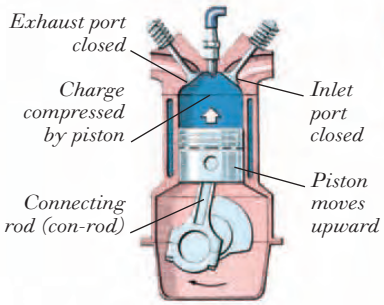


CYCLE OF A FOUR-STROKE INTERNAL COMBUSTION ENGINE

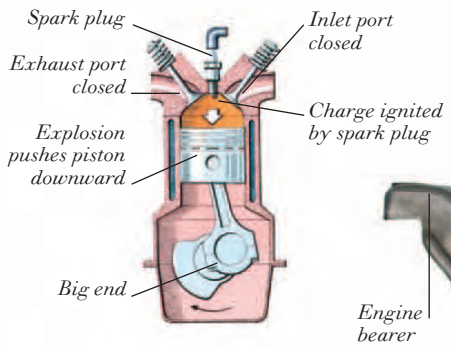
INDUCTION STROKE ("SUCK")



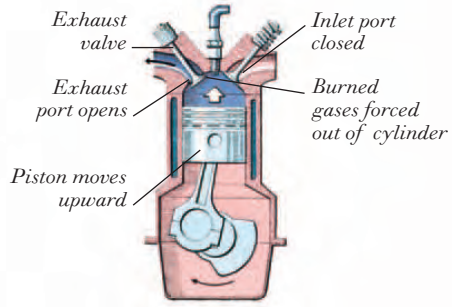
COMPRESSION STROKE ("SQUEEZE")



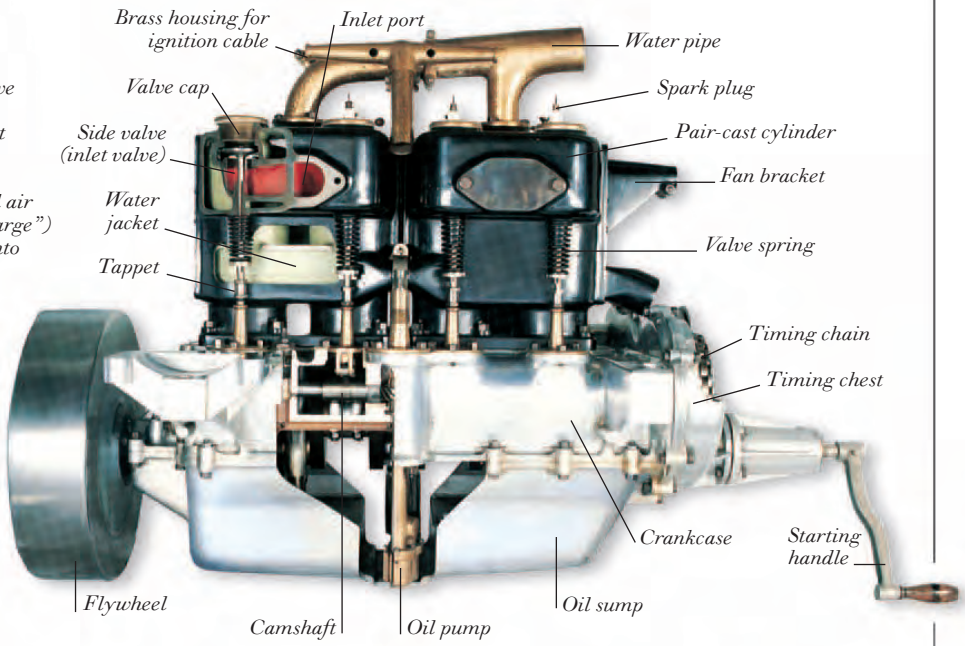
POWER STROKE ("BANG")



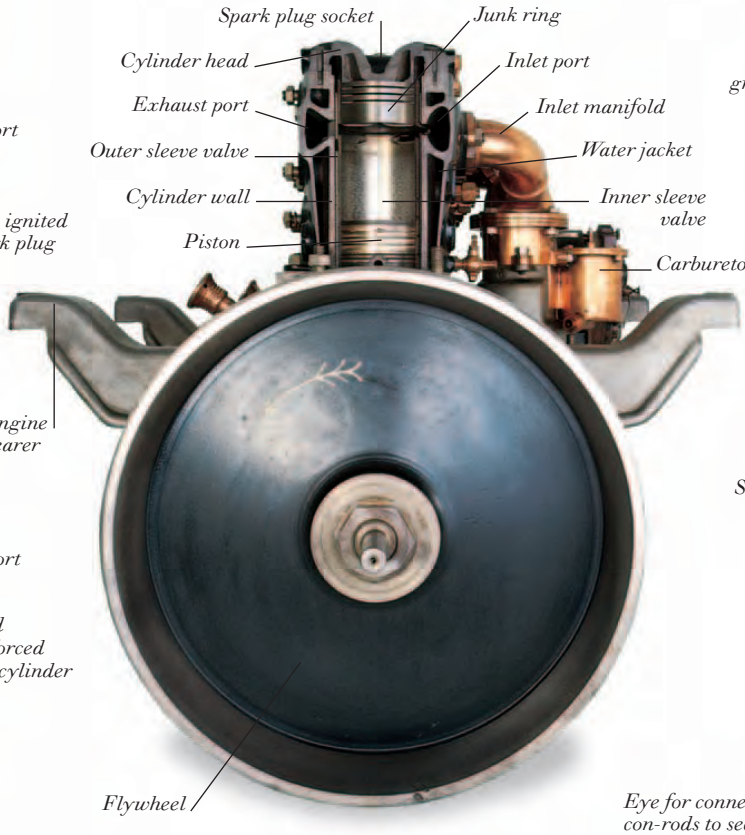
EXHAUST STROKE ("BLOW")



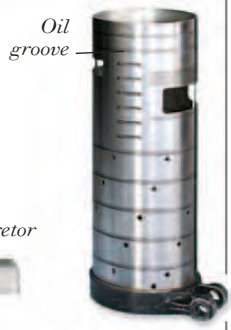
16-HORSEPOWER HUMBER ENGINE, 1911



DAIMLER DOUBLE-SLEEVE VALVE ENGINE, 1910



OUTER SLEEVE VALVE

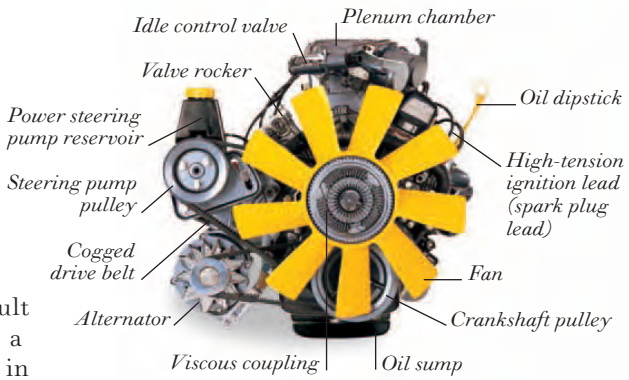


INNER SLEEVE VALVE

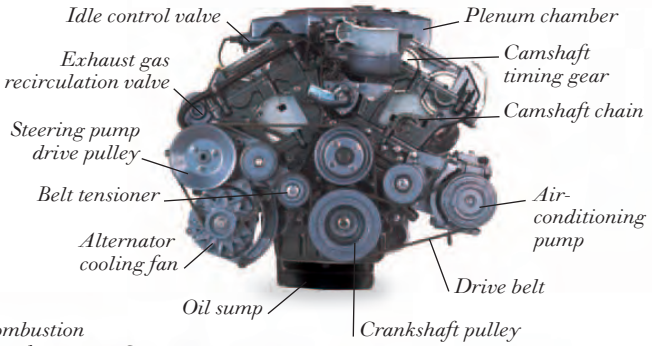
Modern engines

TODAY'S GASOLINE ENGINE WORKS on the same basic principles as the first car engines of a century ago, although it has been greatly refined. Modern engines, often made from special metal alloys, are much lighter than earlier engines. Computerized ignition systems, fuel injectors, and multivalve cylinder heads achieve a more efficient combustion of the fuel/air mixture (the charge) so that less fuel is wasted. As a result of this greater efficiency, the power and performance of a modern engine are increased, and the level of pollution in the exhaust gases is reduced. Exhaust pollution levels today are also lowered by the increasing use of special filters called catalytic converters, which absorb many exhaust pollutants. The need to produce ever more efficient engines means that it can take up to seven years to develop a new engine for a family car, at a cost of many millions of dollars.

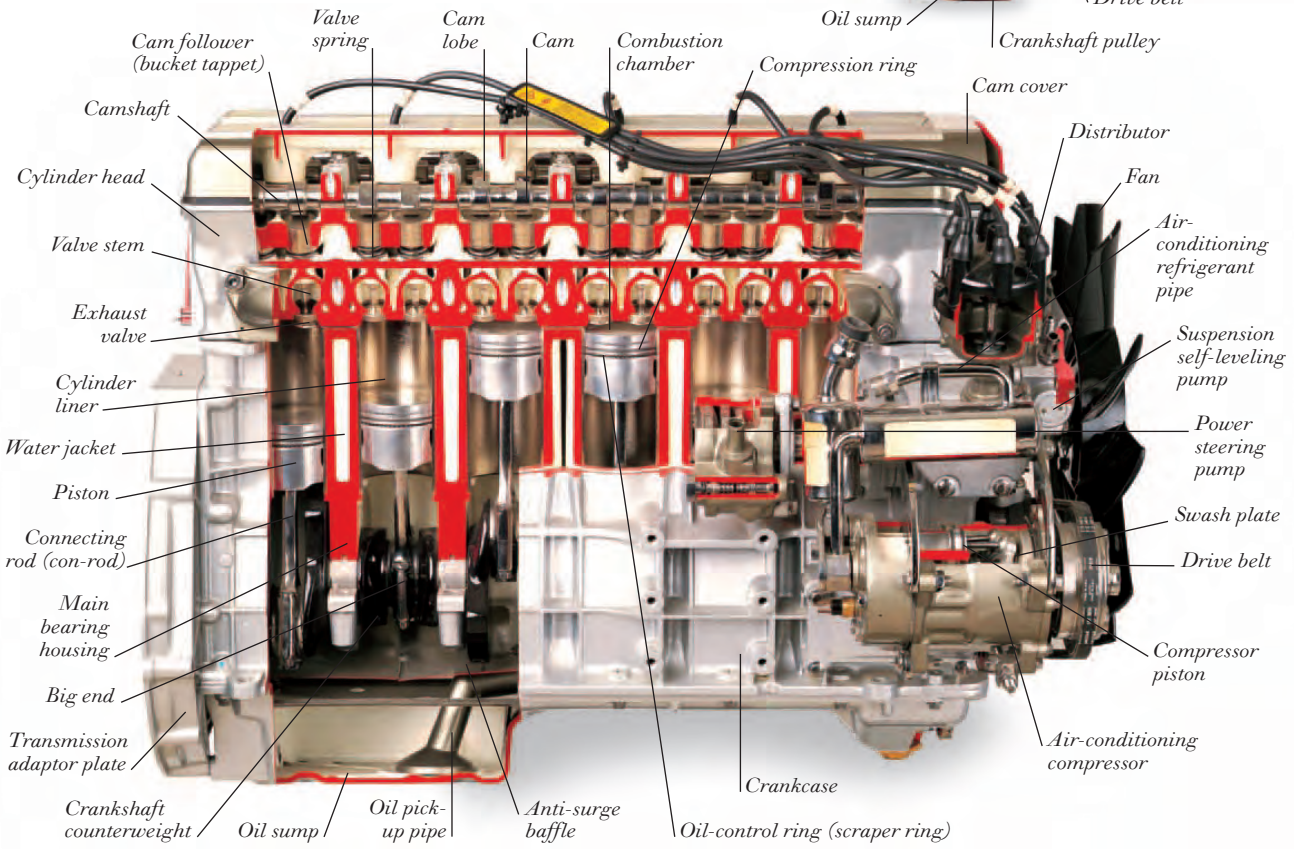
FRONT VIEW OF A FORD COSWORTH V6 12-VALVE



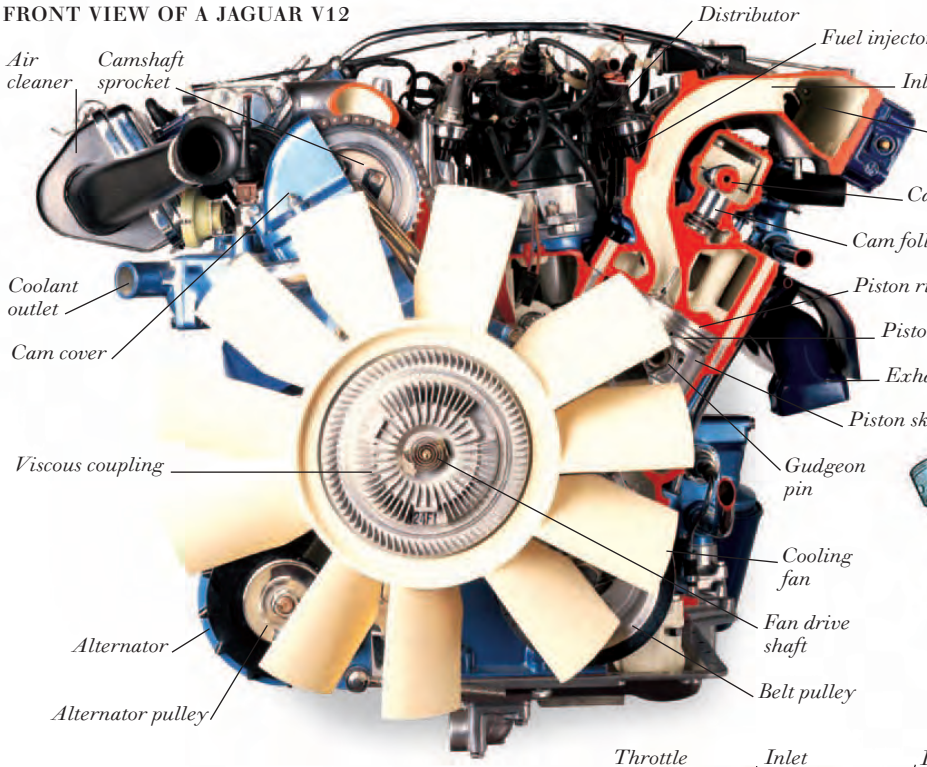
FRONT VIEW OF A FORD COSWORTH V6 24-VALVE

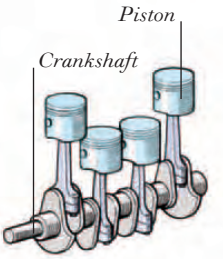


SECTIONED VIEW OF A JAGUAR STRAIGHT 6

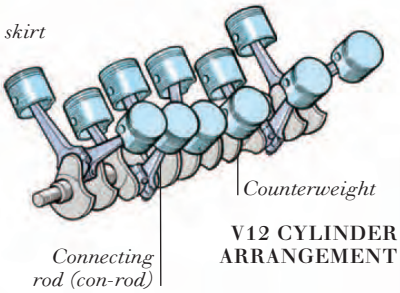


FRONT VIEW OF A JAGUAR V12



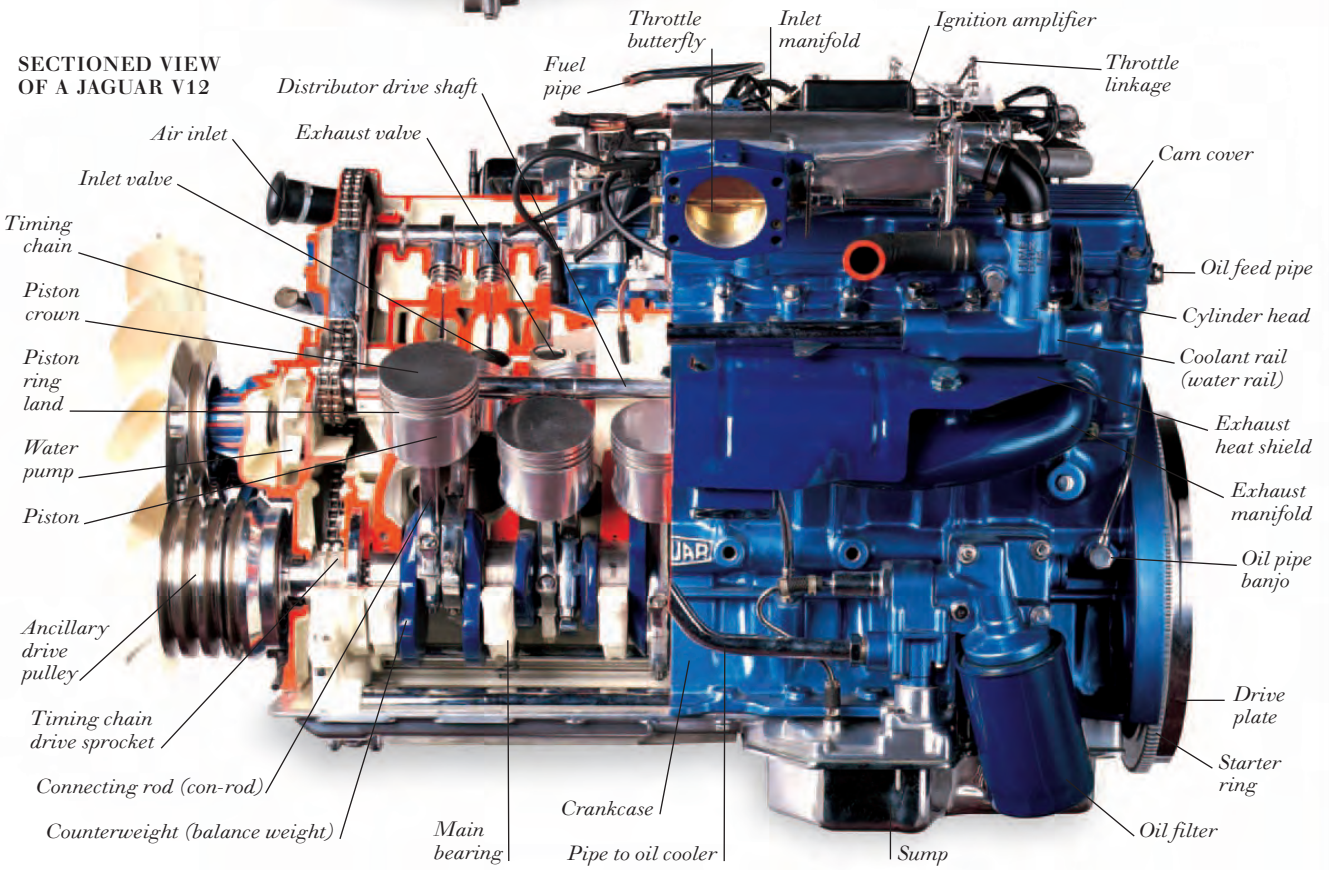


STRAIGHT 4 CYLINDER ARRANGEMENT



V12 CYLINDER ARRANGEMENT

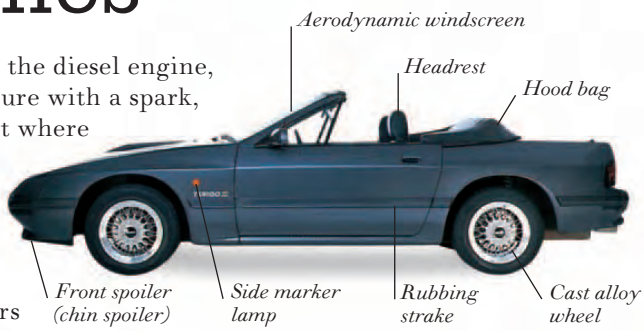
SECTIONED VIEW OF A JAGUAR V12



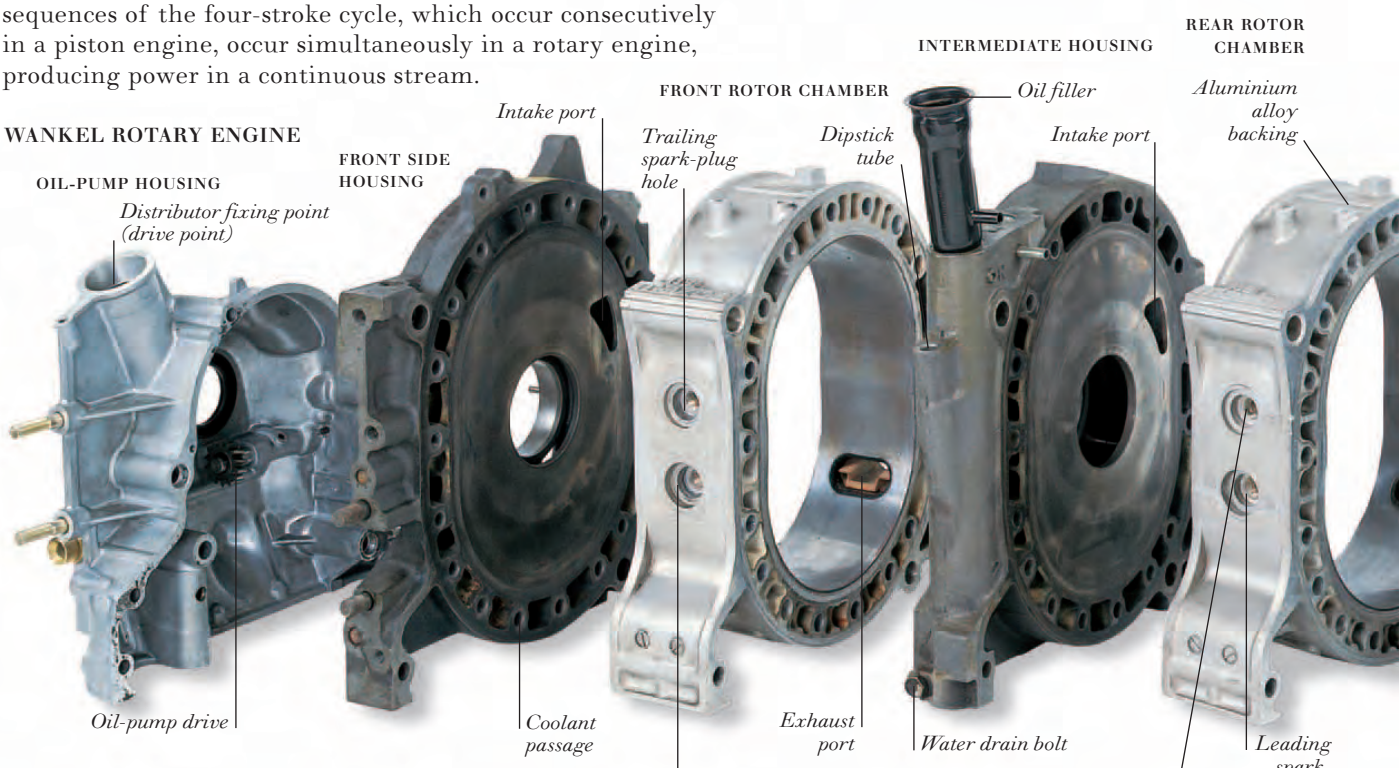
Alternative engines

THE MOST COMMON TYPE OF ALTERNATIVE ENGINE is the diesel engine, which, instead of igniting the compressed fuel/air mixture with a spark, uses compression alone, heating the mixture to the point where it explodes. A diesel engine's fuel consumption is low in comparison with similarly sized piston engines, despite its heavier, reinforced moving parts and cylinder block. Another type of engine is the rotary-combustion, first successfully developed by Felix Wankel in the 1950s. Its two trilobate (three-sided) rotors revolve in housings shaped in a fat figure-eight. The four sequences of the four-stroke cycle, which occur consecutively in a piston engine, occur simultaneously in a rotary engine, producing power in a continuous stream.

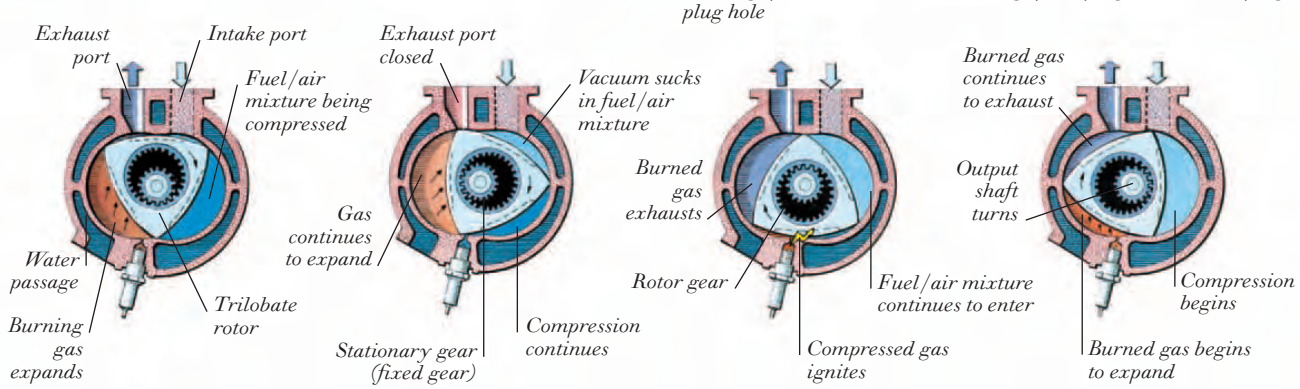
ROTARY-ENGINED MAZDA RX-7



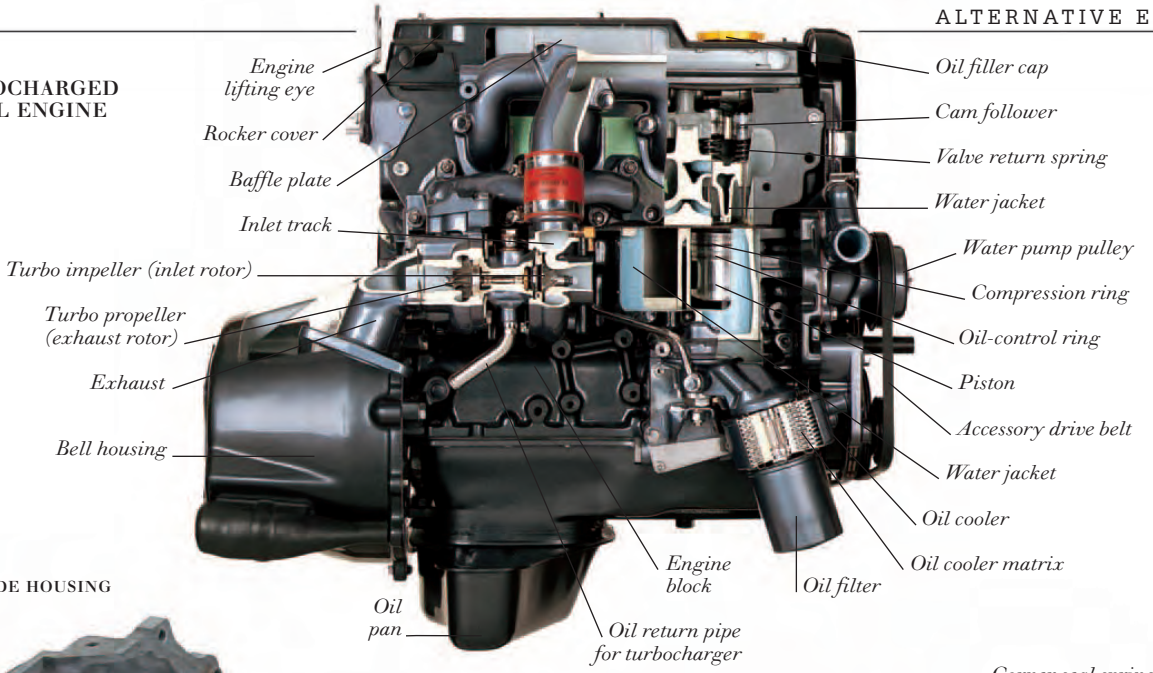
WANKEL ROTARY ENGINE



THE WANKEL ROTARY CYCLE

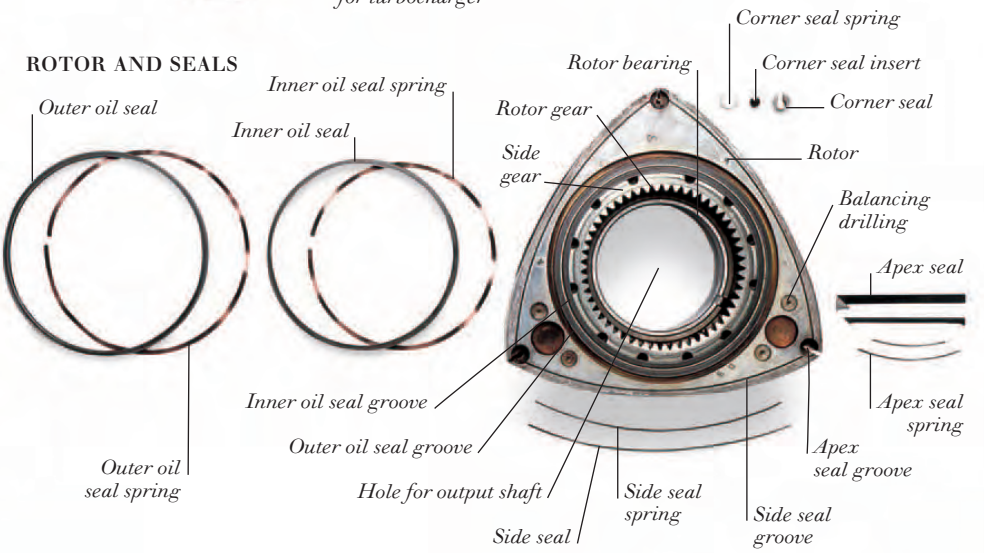


FORD TURBOCHARGED DIESEL ENGINE

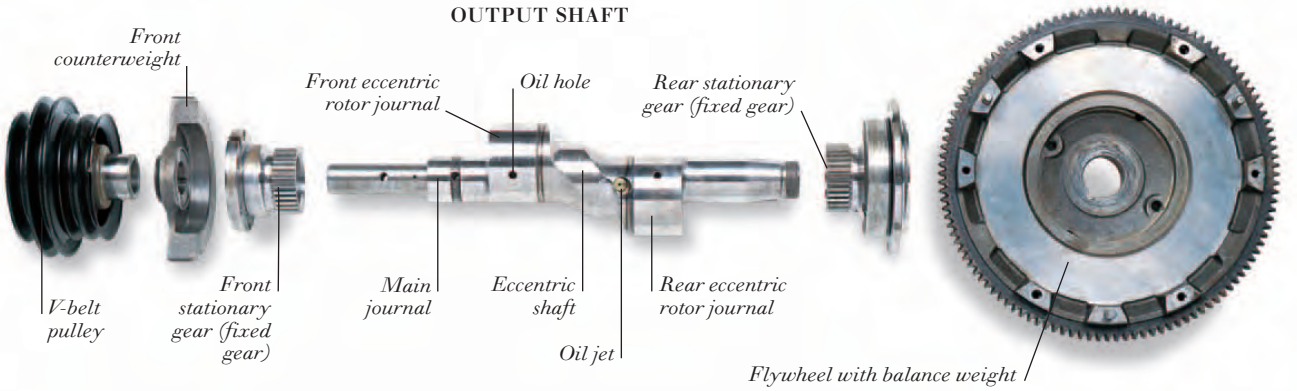


REAR SIDE HOUSING

ROTOR AND SEALS



OUTPUT SHAFT

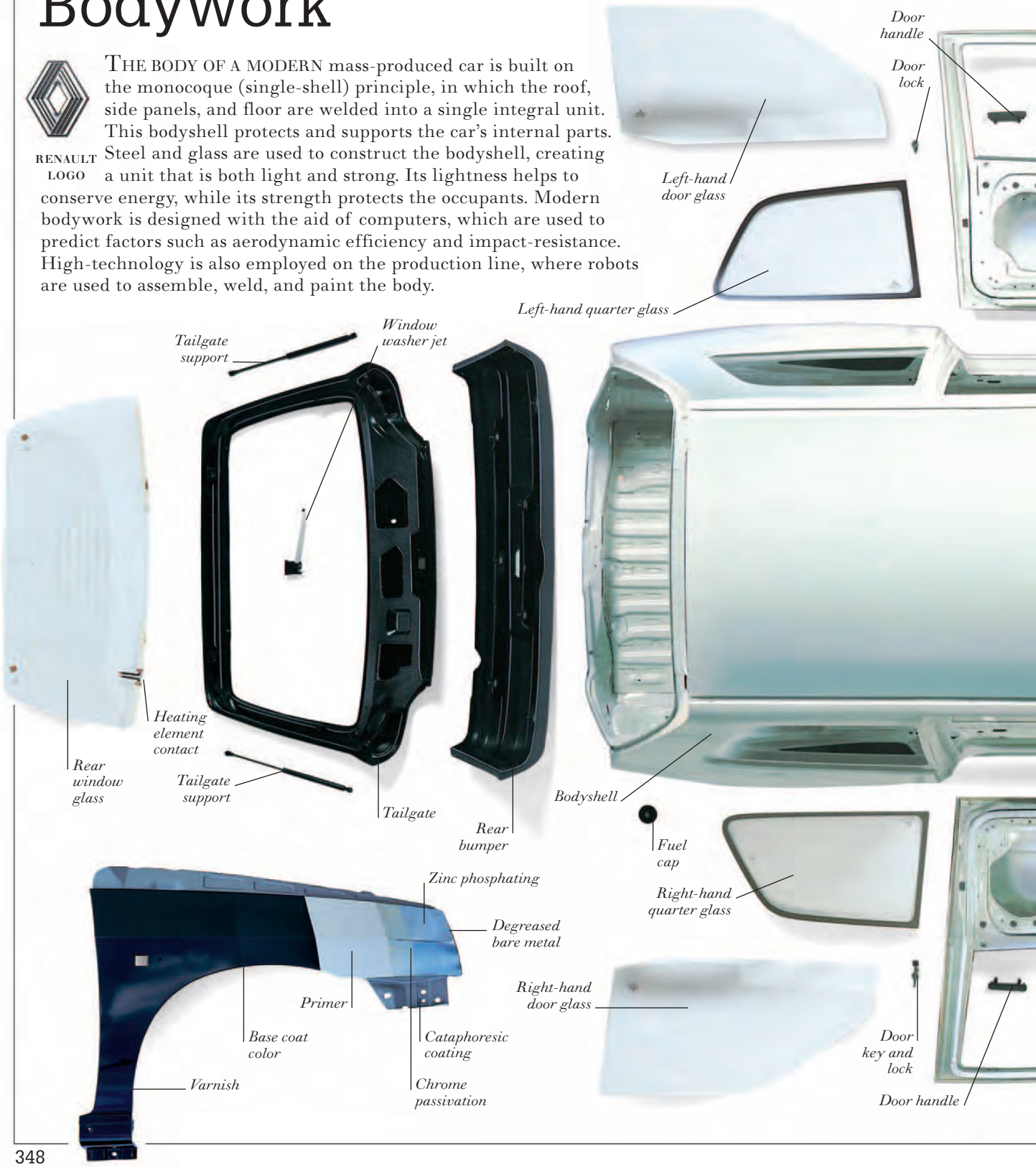


Bodywork

RENAULT LOGO

THE BODY OF A MODERN mass-produced car is built on the monocoque (single-shell) principle, in which the roof, side panels, and floor are welded into a single integral unit. This bodyshell protects and supports the car's internal parts. Steel and glass are used to construct the bodyshell, creating a unit that is both light and strong. Its lightness helps to conserve energy, while its strength protects the occupants. Modern bodywork is designed with the aid of computers, which are used to predict factors such as aerodynamic efficiency and impact-resistance. High-technology is also employed on the production line, where robots are used to assemble, weld, and paint the body.

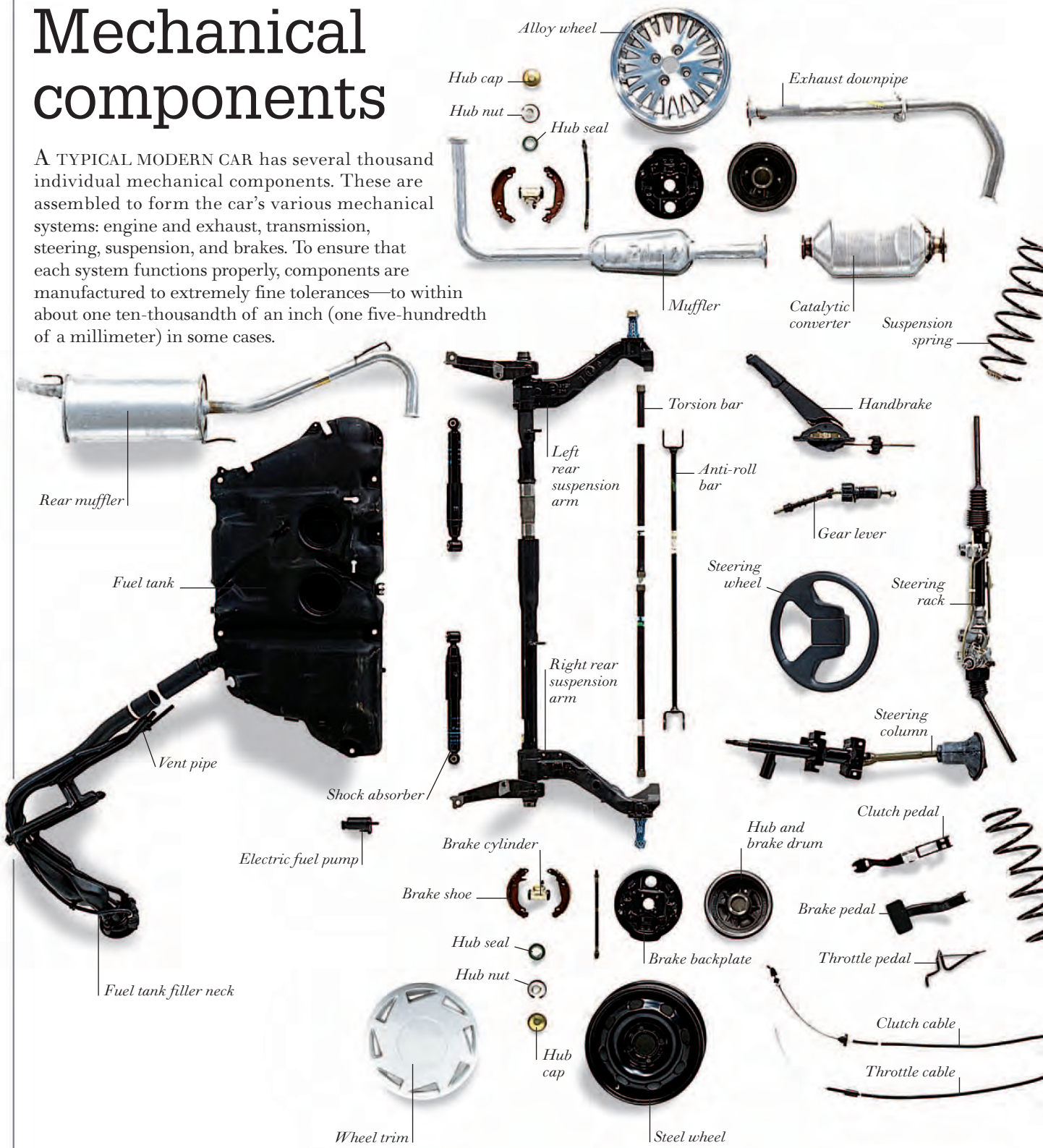
BODYWORK OF A RENAULT CLIO

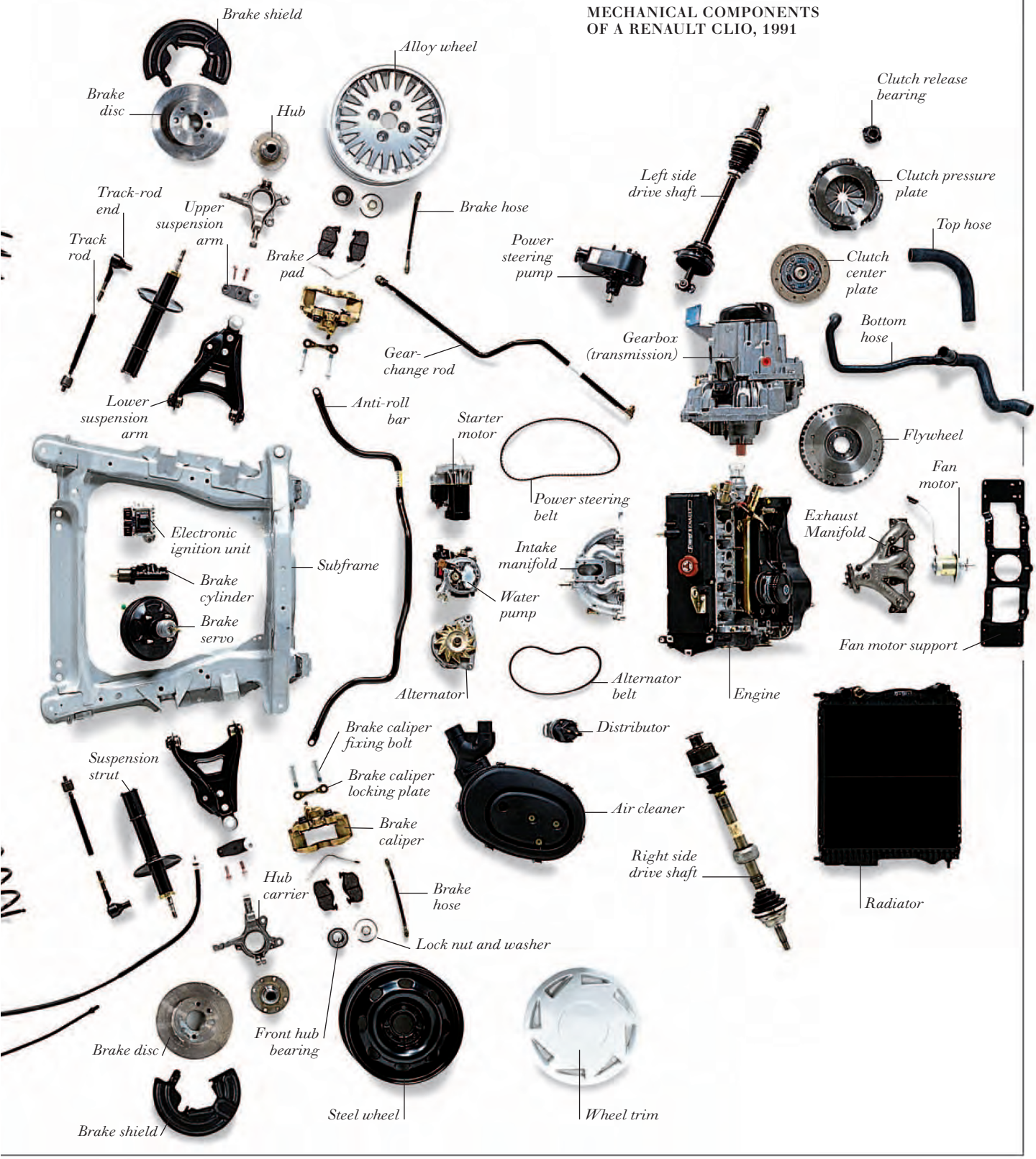


Left-hand door
Left-hand mirror assembly
Door hinge
Electric window motor
Antenna
Rear hatch
Side marker lamp
SIDE VIEW OF A RENAULT CLIO
Hood-release cable
Spoiler bumper
Hood
Hood catch
Hood hinge
Front bumper
Windshield glass
Window winder cable
Window winder handle
Door hinge
Right-hand door
Right-hand mirror assembly
Headrest
Hood
Headlight
Spoiler bumper
Fog-lamp
FRONT VIEW OF A RENAULT CLIO

Mechanical components

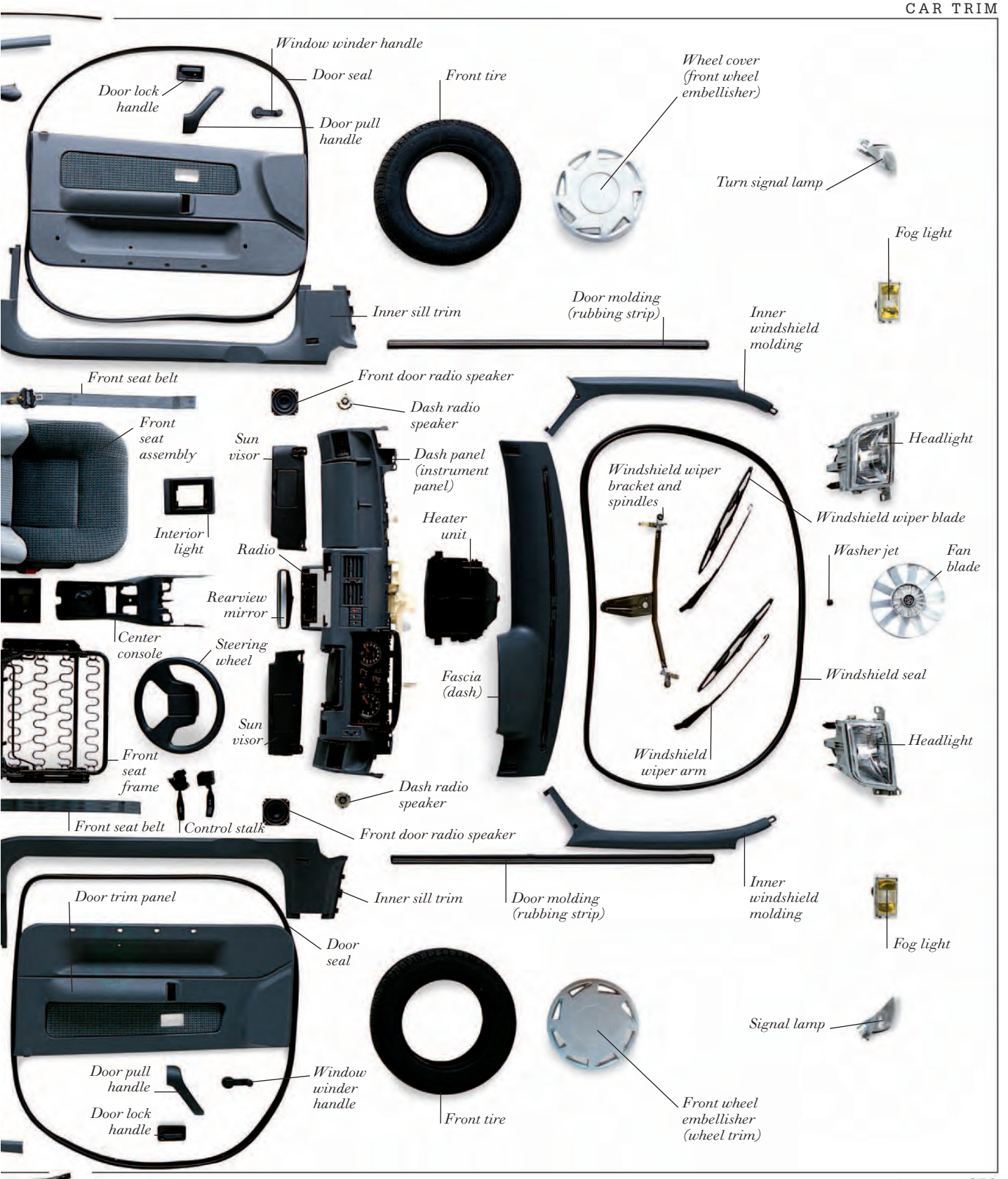
A TYPICAL MODERN CAR has several thousand individual mechanical components. These are assembled to form the car's various mechanical systems: engine and exhaust, transmission, steering, suspension, and brakes. To ensure that each system functions properly, components are manufactured to extremely fine tolerances—to within about one ten-thousandth of an inch (one five-hundredth of a millimeter) in some cases.




MECHANICAL COMPONENTS
OF A RENAULT CLIO, 1991
Brake shield
Alloy wheel
Brake disc
Hub
Clutch release bearing
Left side drive shaft
Clutch pressure plate
Track-rod end
Upper suspension arm
Brake hose
Track rod
Brake pad
Power steering pump
Clutch center plate
Top hose
Gear-change rod
Gearbox (transmission)
Bottom hose
Lower suspension arm
Anti-roll bar
Starter motor
Flywheel
Power steering belt
Fan motor
Electronic ignition unit
Subframe
Intake manifold
Exhaust Manifold
Brake cylinder
Water pump
Brake servo
Fan motor support
Alternator
Alternator belt
Engine
Brake caliper fixing bolt
Distributor
Suspension strut
Brake caliper locking plate
Air cleaner
Brake caliper
Right side drive shaft
Hub carrier
Brake hose
Radiator
Lock nut and washer
Brake disc
Front hub bearing
Steel wheel
Wheel trim
Brake shield

Car trim

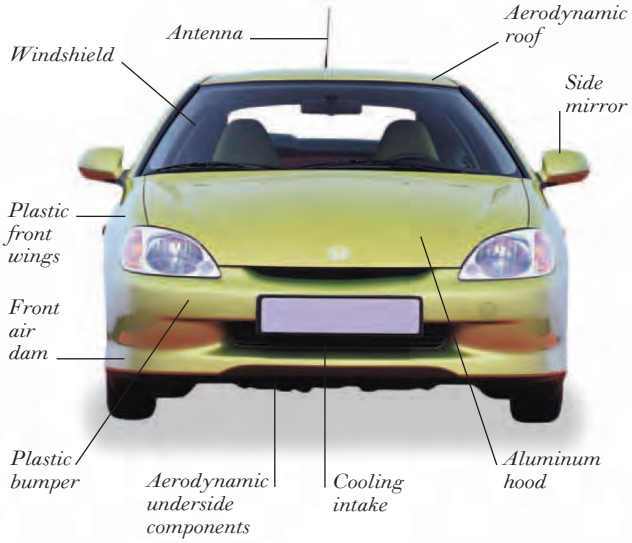
A MODERN CAR HAS TWO TYPES OF TRIM, according to the materials used: hard (chrome and plastics) and soft (upholstery materials). Safety and comfort are priorities in the trim's design: seats help the occupants to maintain a comfortable posture, rubber seals keep out dirt and moisture, and headlights light the way. Older cars had interior or leather paneling cut and fitted by craftsmen; modern cars use precisely molded plastics and seat fabrics cut by robot-controlled lasers to reduce costs and production time. Doors are now trimmed off the production line so that complex wiring can be built in.


Window winder handle
Door seal
Door lock handle
Door pull handle
Front tire
Wheel cover (front wheel embellisher)
Turn signal lamp
Fog light
Inner sill trim
Door molding (rubbing strip)
Inner windshield molding
Front seat belt
Front door radio speaker
Dash radio speaker
Front seat assembly
Sun visor
Dash panel (instrument panel)
Headlight
Windshield wiper bracket and spindles
Windshield wiper blade
Interior light
Heater unit
Radio
Washer jet
Fan blade
Rearview mirror
Center console
Steering wheel
Windshield seal
Fascia (dash)
Sun visor
Headlight
Front seat frame
Windshield wiper arm
Dash radio speaker
Front seat belt
Control stalk
Front door radio speaker
Door trim panel
Inner sill trim
Door molding (rubbing strip)
Inner windshield molding
Door seal
Fog light
Signal lamp
Door pull handle
Window winder handle
Door lock handle
Front tire
Front wheel embellisher (wheel trim)

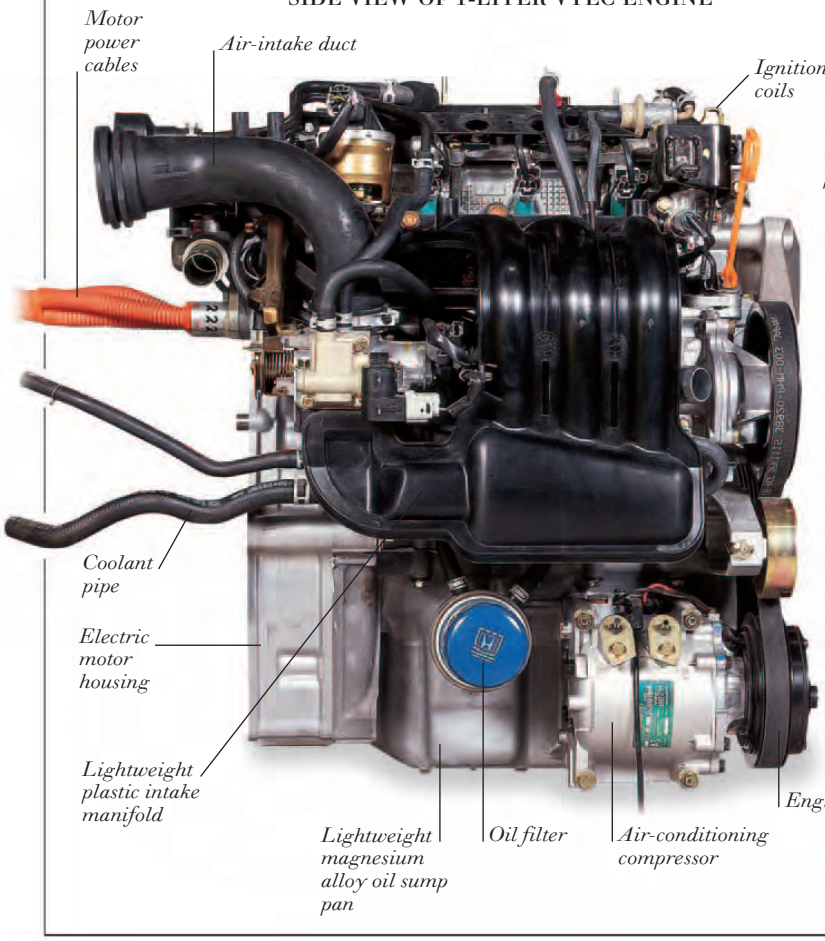
Hybrid car

THERE HAVE BEEN SEVERAL proposed alternatives to conventional gas- or diesel-powered cars, including cars that use solar or battery power. The object is to lower harmful emissions and conserve natural resources. One of the alternatives already in production is the hybrid car. A hybrid vehicle uses two or more fuels. Examples include diesel-electric trains and mopeds. The latter combine the power of a gasoline engine with pedal power. In a hybrid car, gas consumption is reduced by the provision of additional power by an electric motor during acceleration. The motor is driven by power from on-board batteries that are recharged by an engine-driven generator when the car is decelerating or cruising. Some hybrid cars transfer energy from the wheels to a flywheel during braking. The flywheel drives the generator, which recharges the batteries.

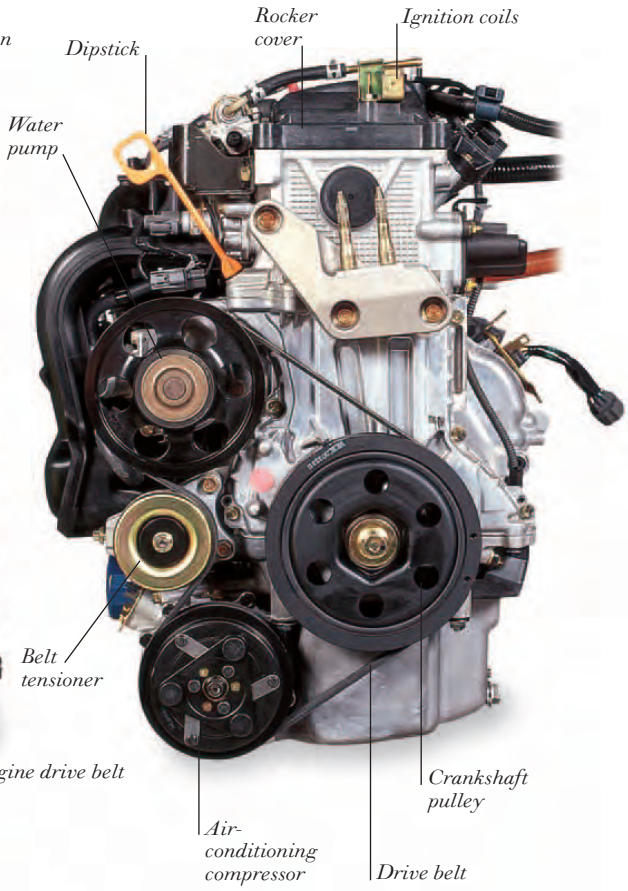
HONDA INSIGHT



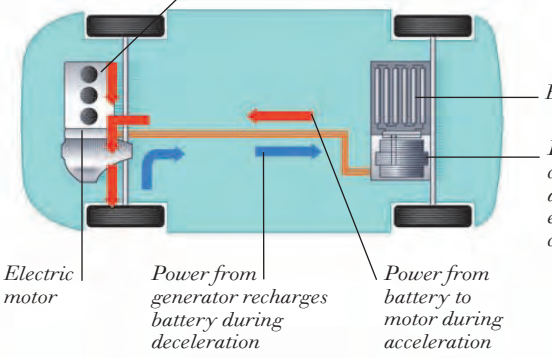
SIDE VIEW OF 1-LITER VTEC ENGINE



FRONT VIEW OF 1-LITER VTEC ENGINE

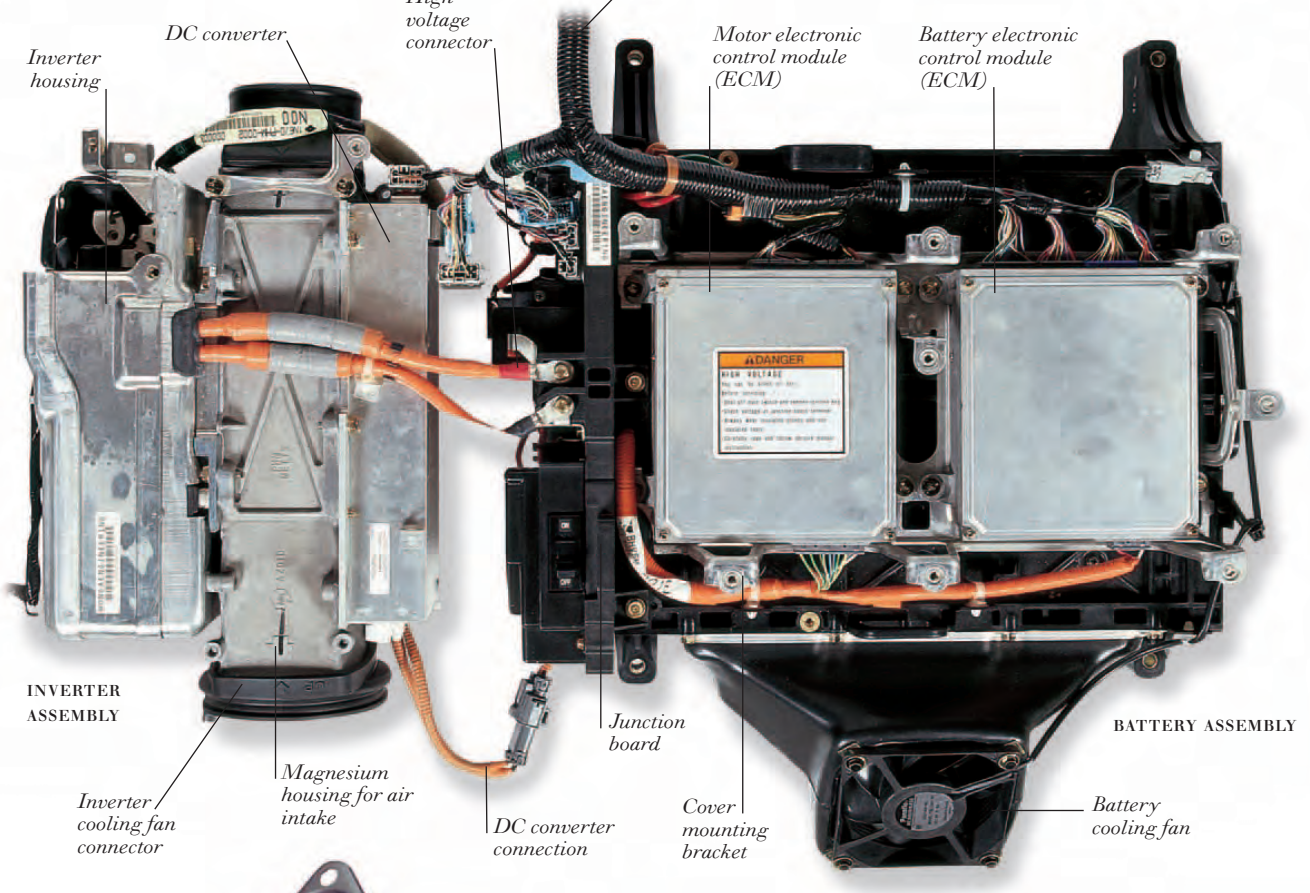


HOW HYBRID POWER WORKS



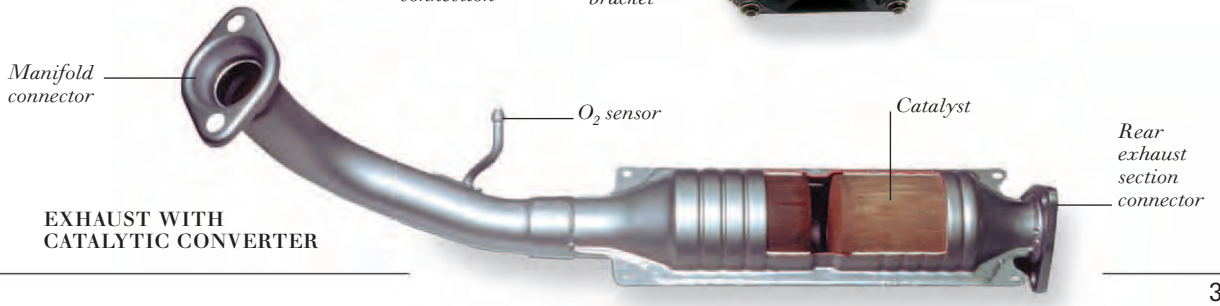
REAR VIEW

INVERTER AND BATTERY



INVERTER ASSEMBLY

BATTERY ASSEMBLY

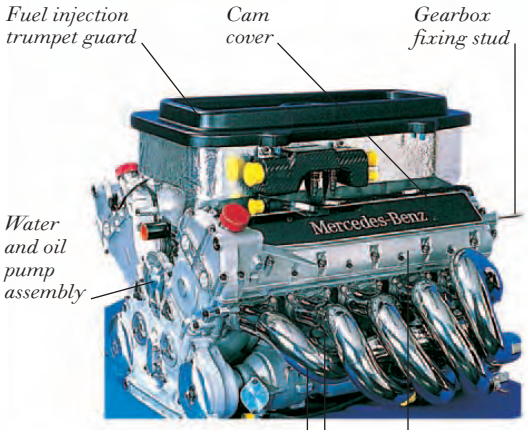


EXHAUST WITH CATALYTIC CONVERTER

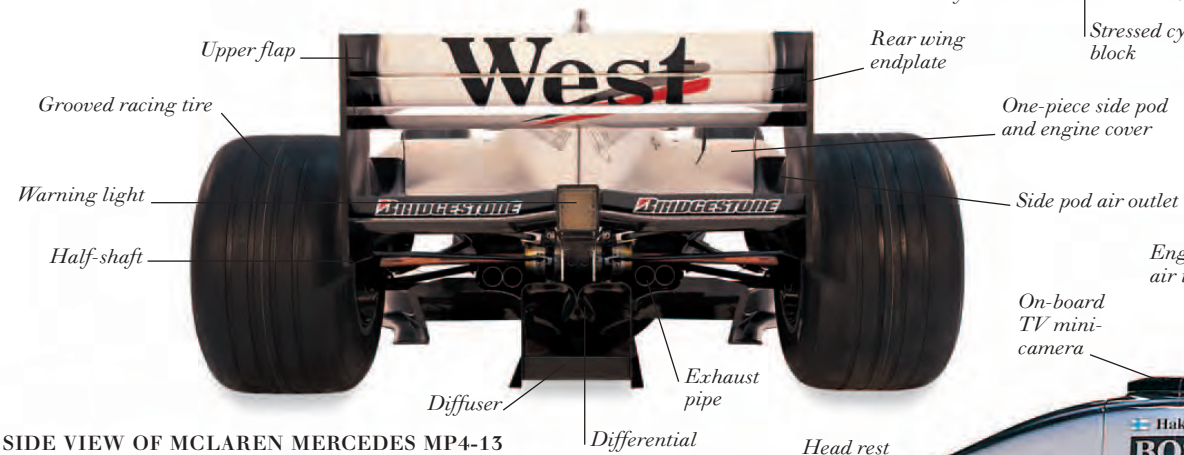
Race cars

SINCE THE ADVENT OF DRIVING, race cars have been a major focus of innovation in car design. Features that are now commonplace, such as disc brakes, turbochargers, and even safety belts, were used first on competition cars. Research into race cars has contributed to a new understanding of engine performance, aerodynamics, and tire adhesion, and has led to the development of ultralight materials such as carbon fiber for car bodies. A modern McLaren Formula One car has a low, streamlined body and an open cockpit but, unlike its forerunner, it also has front and rear wings that push the wheels firmly on to the track, huge tires for extra grip, and electronic sensors that continually relay information to the pits about the car's performance.

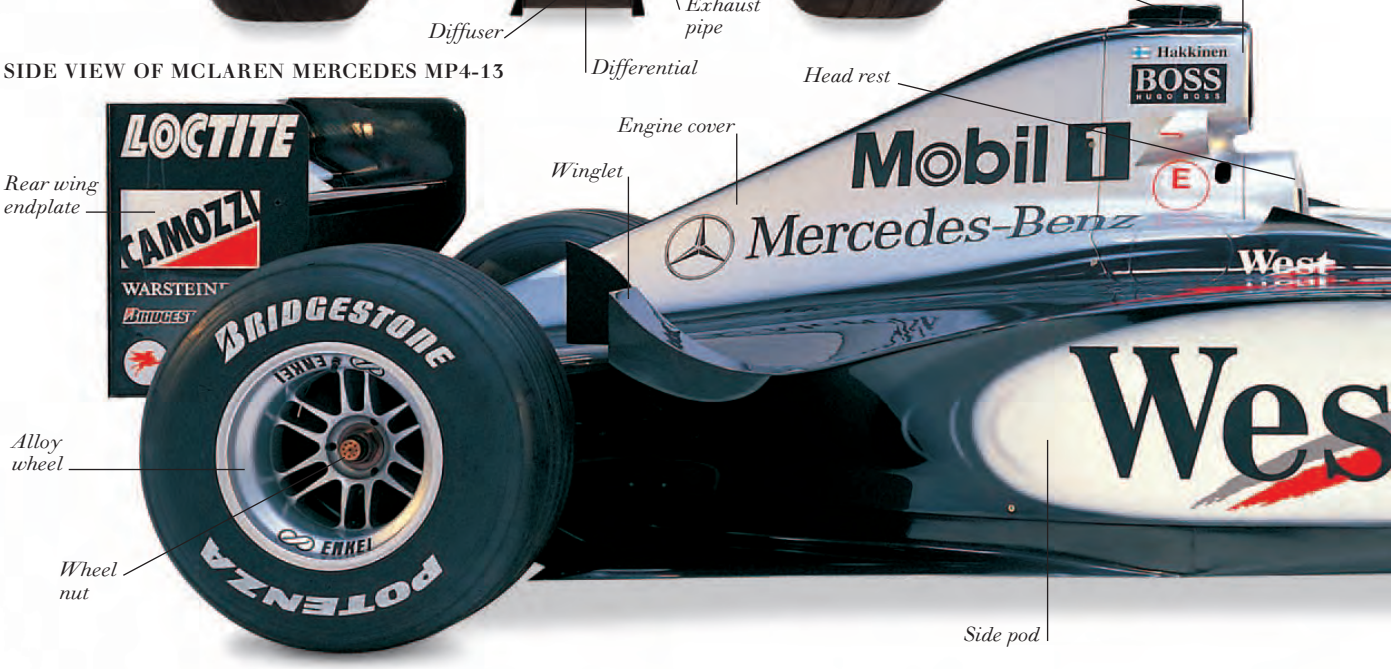
72° V10 ENGINE



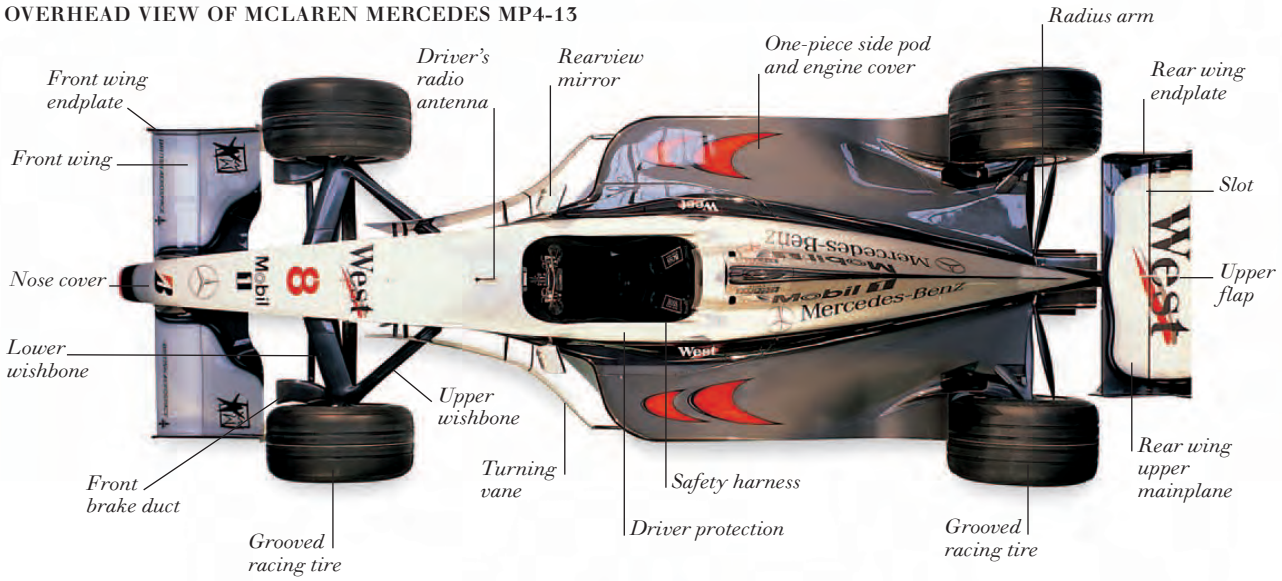
BACK VIEW OF MCLAREN MERCEDES MP4-13



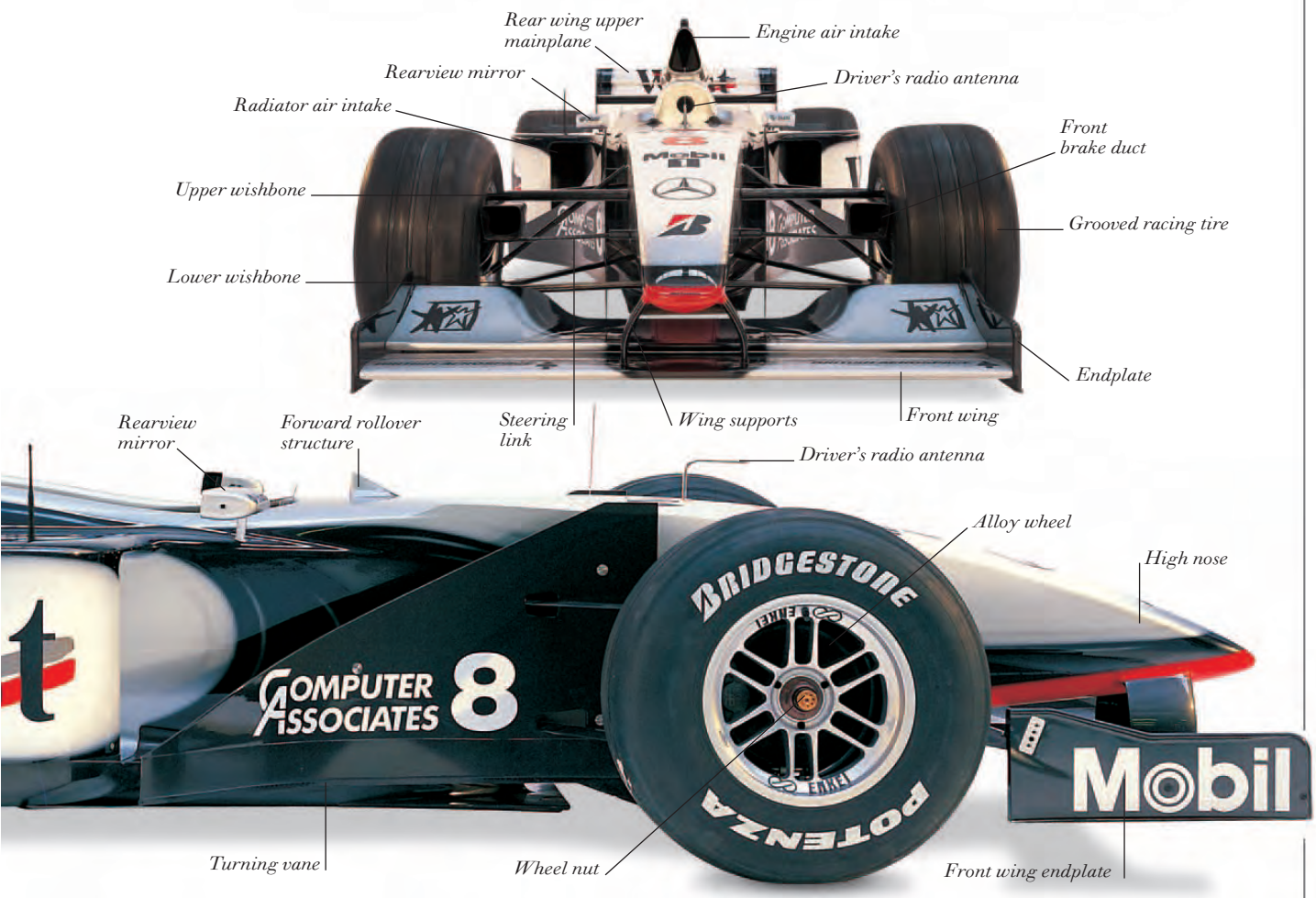
SIDE VIEW OF MCLAREN MERCEDES MP4-13



OVERHEAD VIEW OF MCLAREN MERCEDES MP4-13

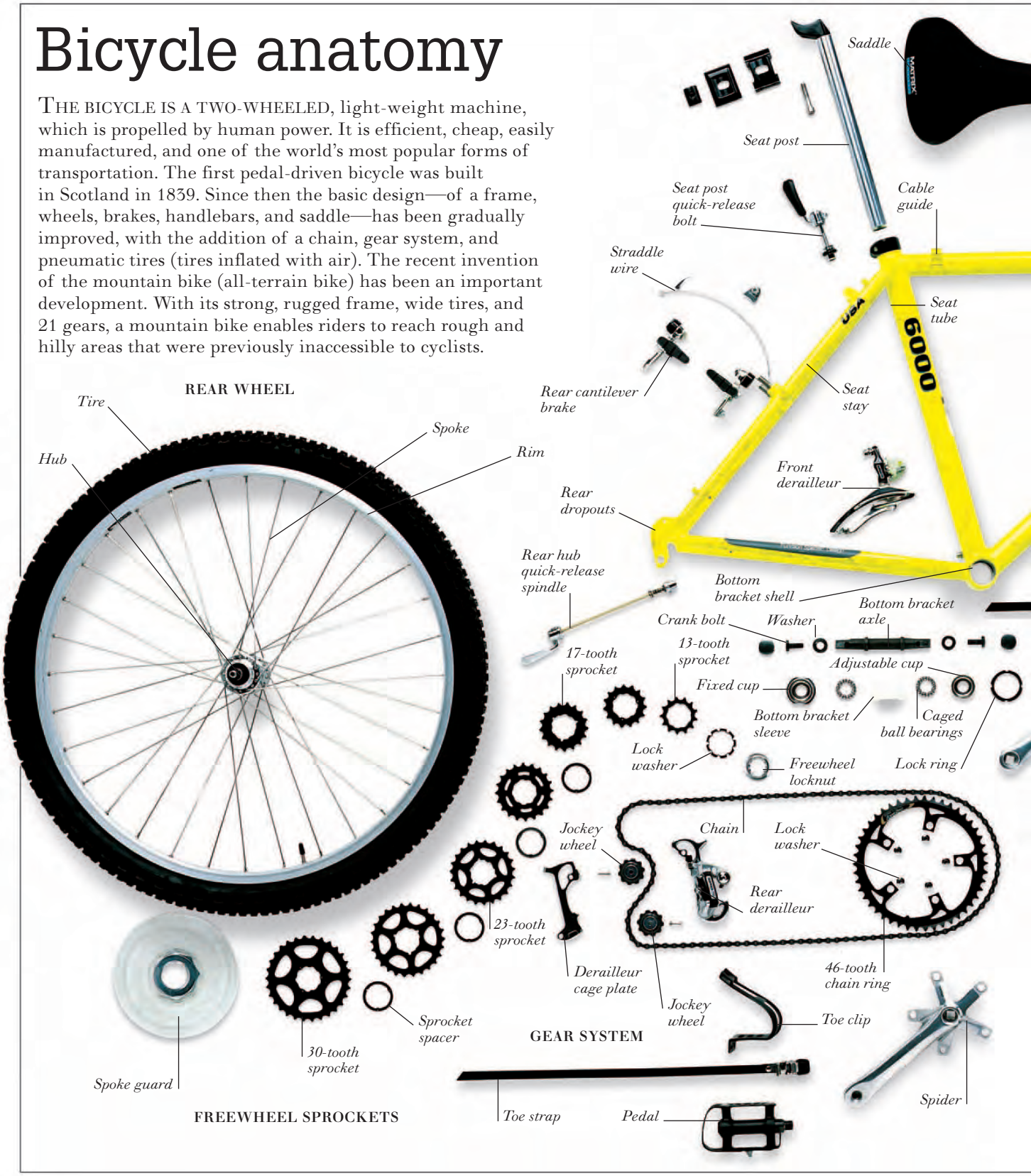


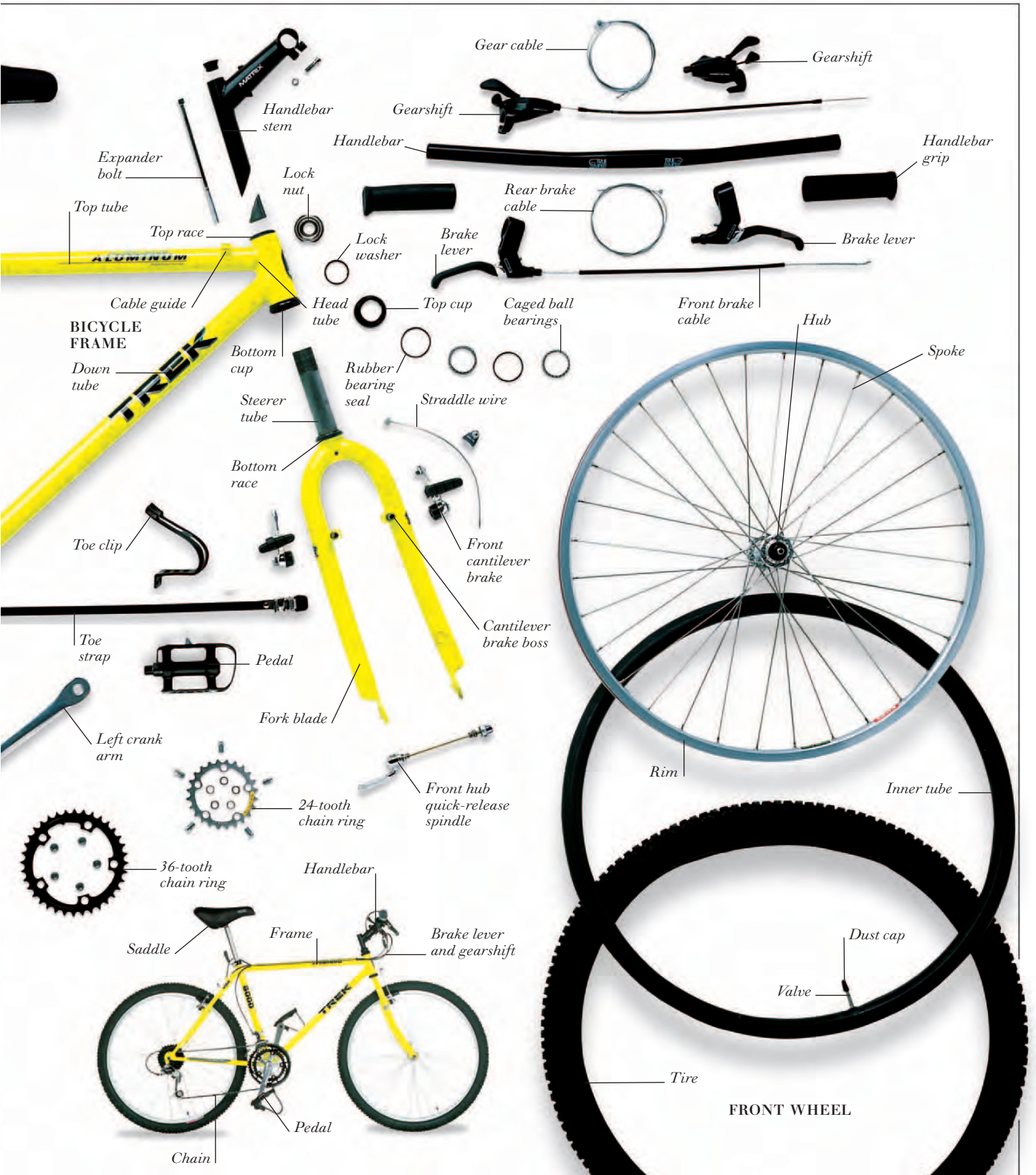
FRONT VIEW OF MCLAREN MERCEDES MP4-13



Bicycle anatomy

THE BICYCLE IS A TWO-WHEELED, light-weight machine, which is propelled by human power. It is efficient, cheap, easily manufactured, and one of the world's most popular forms of transportation. The first pedal-driven bicycle was built in Scotland in 1839. Since then the basic design—of a frame, wheels, brakes, handlebars, and saddle—has been gradually improved, with the addition of a chain, gear system, and pneumatic tires (tires inflated with air). The recent invention of the mountain bike (all-terrain bike) has been an important development. With its strong, rugged frame, wide tires, and 21 gears, a mountain bike enables riders to reach rough and hilly areas that were previously inaccessible to cyclists.




Gear cable
Gearshift
Handlebar stem
Gearshift
Handlebar
Handlebar grip
Expander bolt
Lock nut
Rear brake cable
Top tube
Top race
Lock washer
Brake lever
Brake lever
Cable guide
Head tube
Top cup
Caged ball bearings
Front brake cable
BICYCLE FRAME
Hub
Bottom cup
Spoke
Down tube
Rubber bearing seal
Steerer tube
Straddle wire
Bottom race
Front cantilever brake
Toe clip
Cantilever brake boss
Toe strap
Pedal
Fork blade
Left crank arm
Rim
Inner tube
24-tooth chain ring
Front hub quick-release spindle
36-tooth chain ring
Handlebar
Saddle
Frame
Brake lever and gearshift
Dust cap
Valve
Tire
FRONT WHEEL
Pedal
Chain

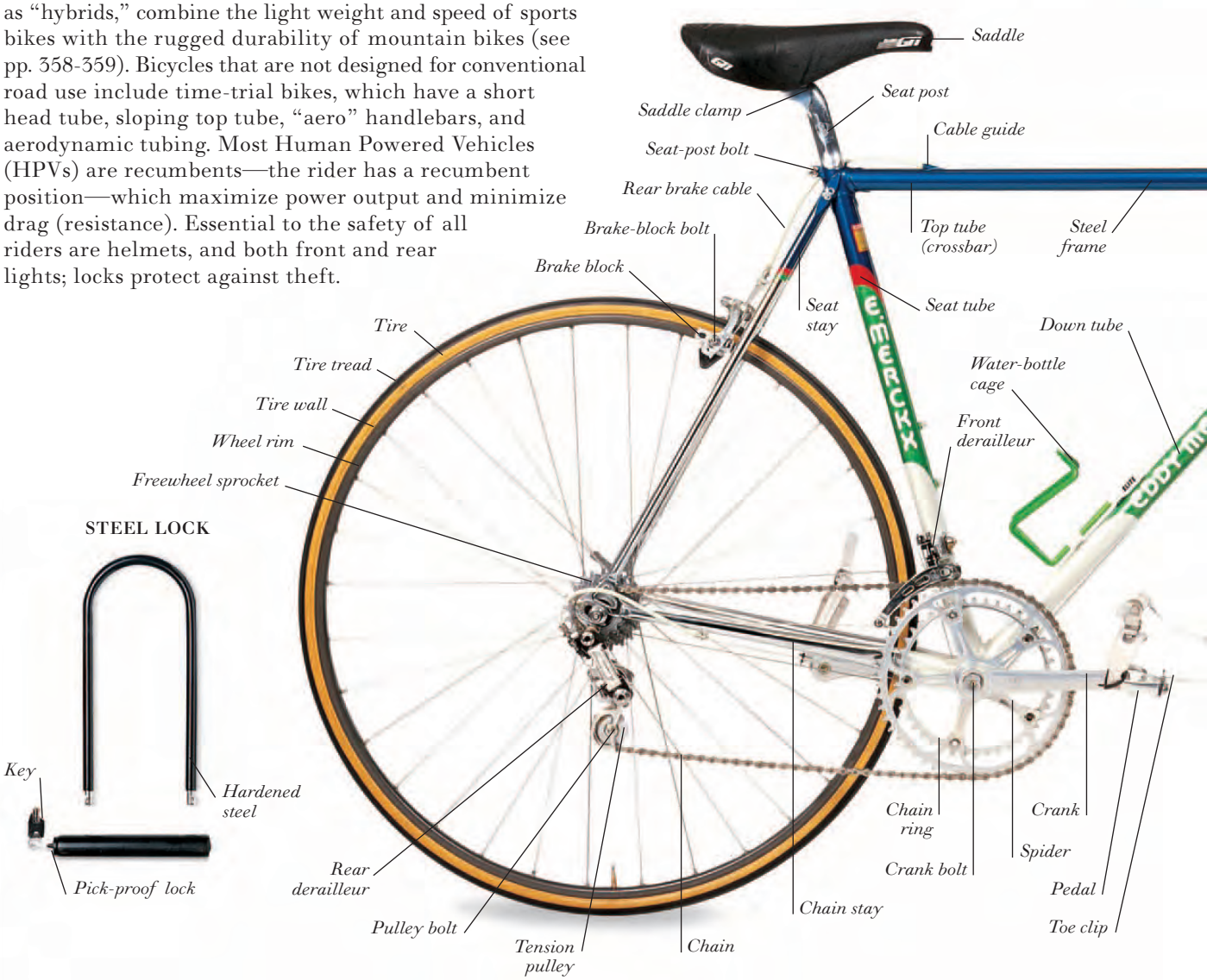
Bicycles

ALTHOUGH ALL BICYCLES are made up of the same basic components, they can vary greatly in design. A racing bike, such as the Eddy Merckx model, with its light frame and steep head- and seat-angles, is built for speed. Its design forces the rider to adopt the "aerotuck," a crouched, aerodynamic position. While a touring bike resembles the racing bike in many respects, it is designed for comfort and stability on long-distance journeys. Touring bikes are characterized by more relaxed frame angles, heavy chain stays that support the rear panniers, and a long wheelbase (the distance between the wheel axles) for reliable handling. All-round bicycles, known as "hybrids," combine the light weight and speed of sports bikes with the rugged durability of mountain bikes (see pp. 358-359). Bicycles that are not designed for conventional road use include time-trial bikes, which have a short head tube, sloping top tube, "aero" handlebars, and aerodynamic tubing. Most Human Powered Vehicles (HPVs) are recumbents—the rider has a recumbent position—which maximize power output and minimize drag (resistance). Essential to the safety of all riders are helmets, and both front and rear lights; locks protect against theft.

FRONT AND REAR LIGHTS

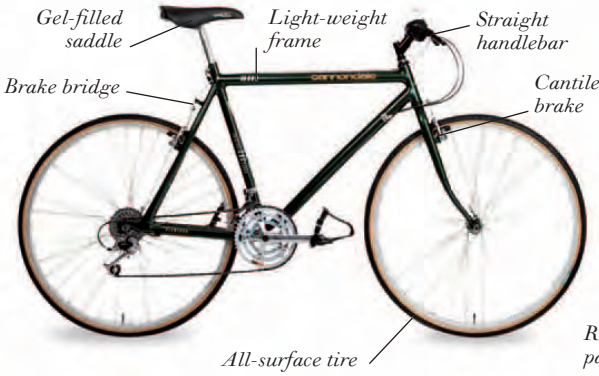
HELMET

EDDY MERCKX RACING BICYCLE



STEEL LOCK

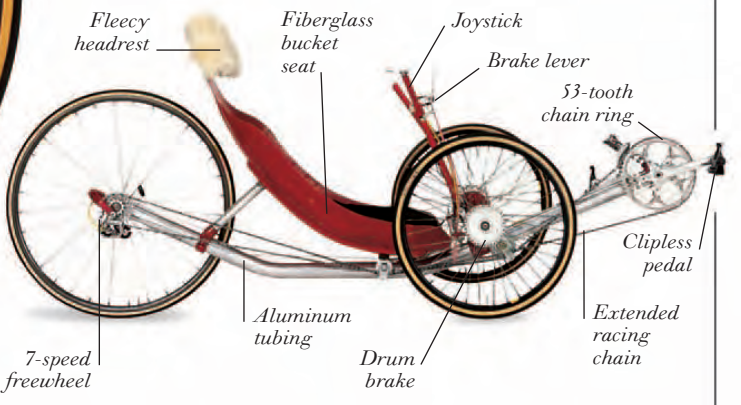
CANNONDALE SH600 HYBRID BICYCLE



CANNONDALE ST1000 TOURING BICYCLE

ROSSIN ITALIAN TIME-TRIAL BICYCLE

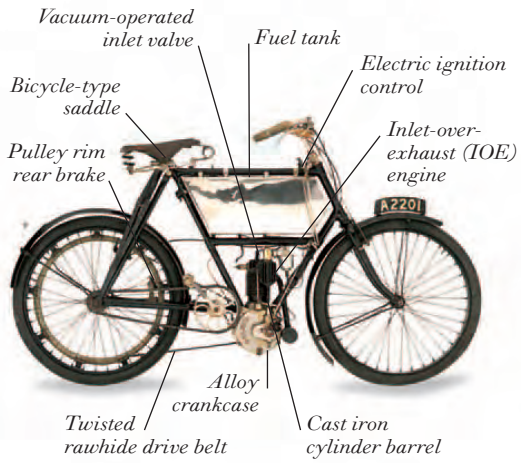
WINDCHEETAH SL MARK VI "SPEEDY" RACING HPV BICYCLE



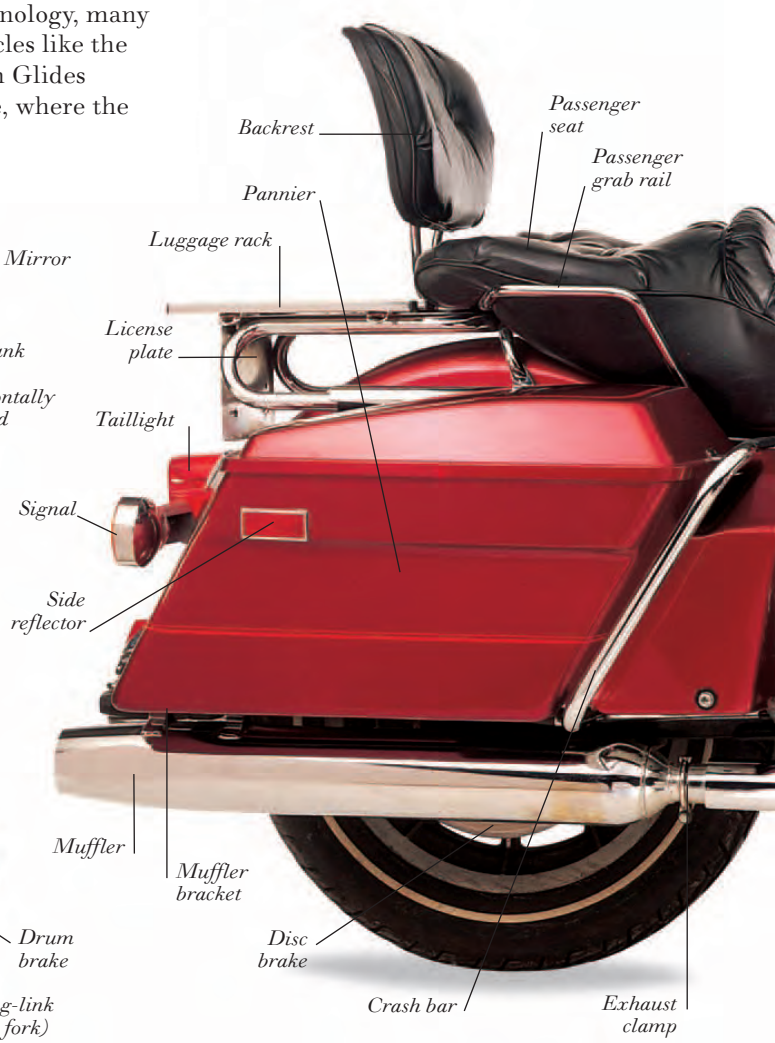
The motorcycle

THE MOTORCYCLE HAS EVOLVED from a motorized cycle—a basic bicycle with an engine—into a sophisticated, high-performance machine. In 1901, the Werner brothers established the most viable location for the engine by positioning it low in the center of the chassis (see pp. 364-365): the new Werner became the basis for the modern motorcycle. Motorcycles are used for many purposes—for commuting, delivering messages, touring, and racing—and different machines have been developed according to the demands of different types of rider. The Vespa scooter, for instance, which is small-wheeled, economical, and easy-to-ride, was designed to meet the needs of the commuter. Sidecars provided transportation for the family until the arrival of cheap cars caused their popularity to decline. Enthusiast riders generally favor larger capacity machines that are capable of greater performance and offer more comfort. Four-cylinder machines have been common since the Honda CB750 appeared in 1969. Despite advances in motorcycle technology, many riders are attracted to the traditional looks of motorcycles like the twin-cylinder Harley-Davidson. The Harley-Davidson Glides exploit the style of the classic American V-twin engine, where the cylinders are placed in a V-formation.

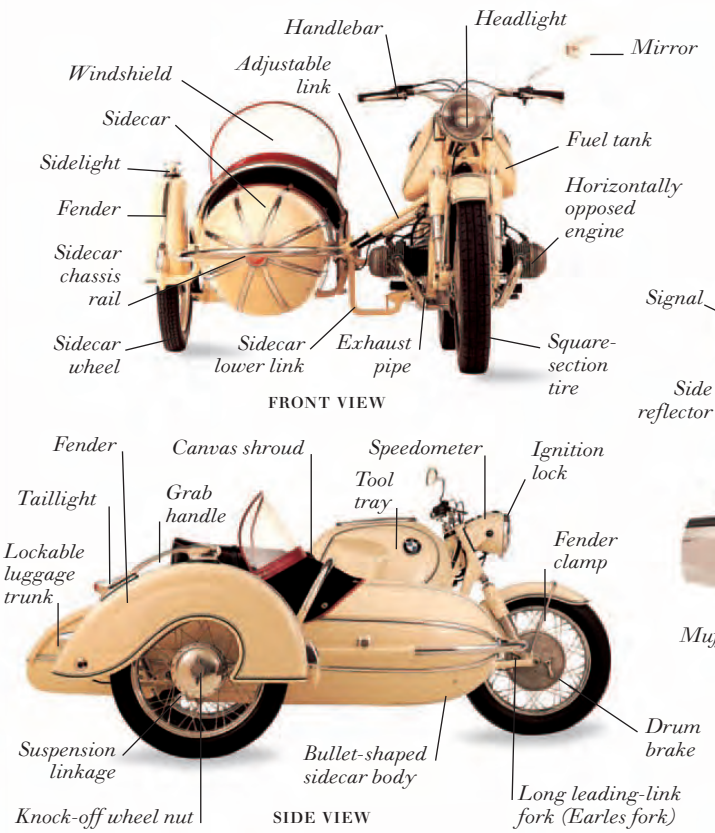
1901 WERNER MOTORCYCLE

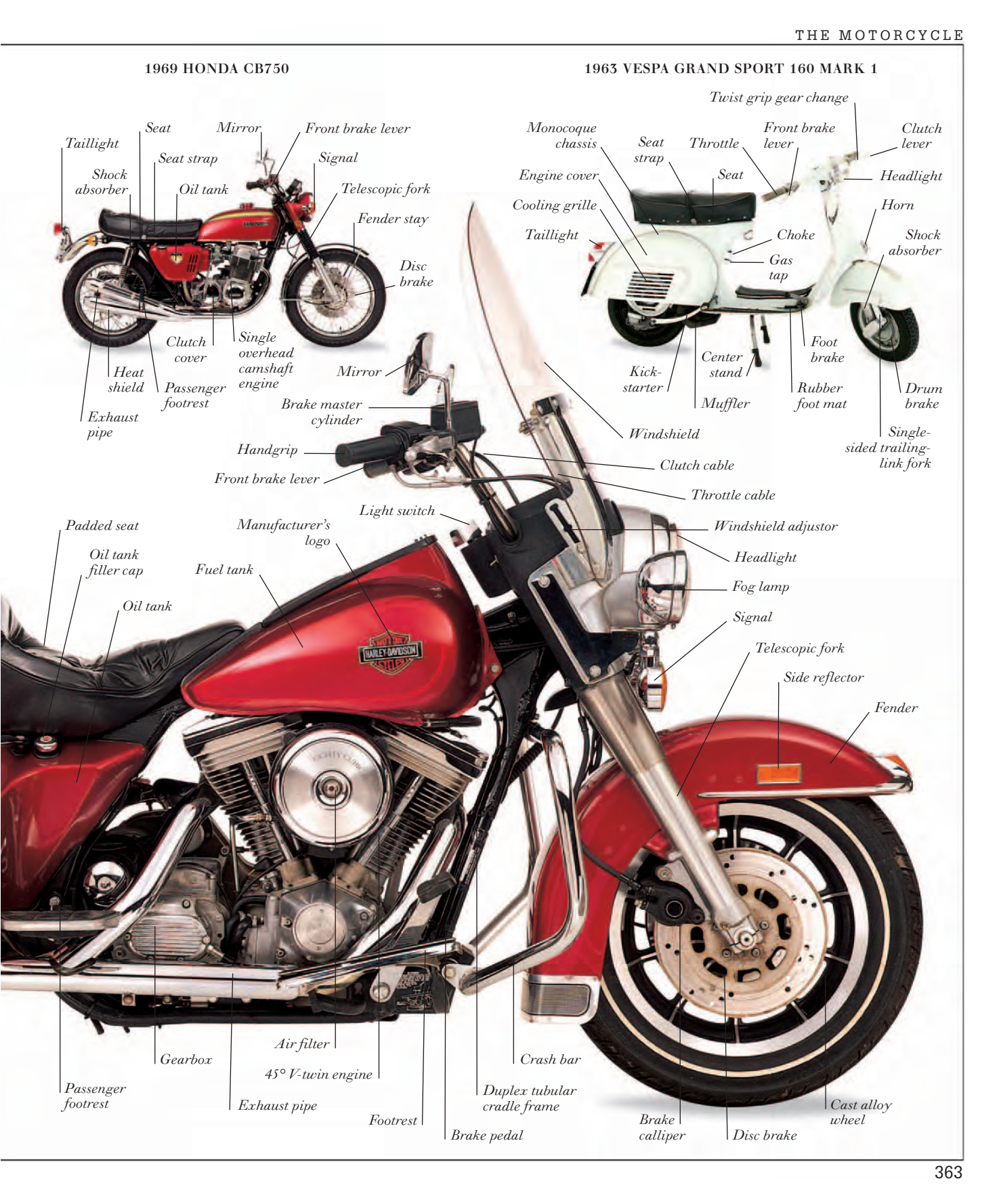


1988 HARLEY-DAVIDSON FLHS ELECTRA GLIDE



1965 BMW R/60 WITH 1952 STEIB CHAIR

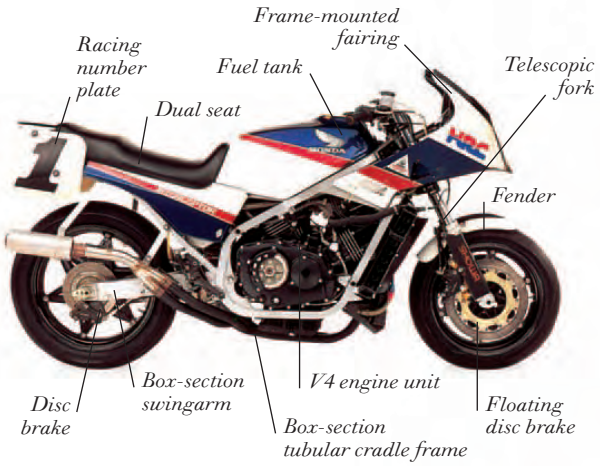



1969 HONDA CB750
Taillight
Seat
Mirror
Front brake lever
Seat strap
Signal
Shock absorber
Oil tank
Telescopic fork
Fender stay
Disc brake
Clutch cover
Single overhead camshaft engine
Heat shield
Passenger footrest
Exhaust pipe
1963 VESPA GRAND SPORT 160 MARK 1
Twist grip gear change
Monocoque chassis
Seat strap
Throttle
Front brake lever
Clutch lever
Engine cover
Seat
Headlight
Cooling grille
Horn
Taillight
Choke
Shock absorber
Gas tap
Foot brake
Kick-starter
Center stand
Rubber foot mat
Drum brake
Muffler
Single-sided trailing-link fork
Mirror
Windshield
Brake master cylinder
Handgrip
Clutch cable
Front brake lever
Throttle cable
Light switch
Padded seat
Manufacturer's logo
Windshield adjustor
Oil tank filler cap
Headlight
Fuel tank
Fog lamp
Oil tank
Signal
Telescopic fork
Side reflector
Fender
Air filter
Gearbox
45° V-twin engine
Crash bar
Passenger footrest
Exhaust pipe
Duplex tubular cradle frame
Footrest
Brake pedal
Brake calliper
Disc brake
Cast alloy wheel

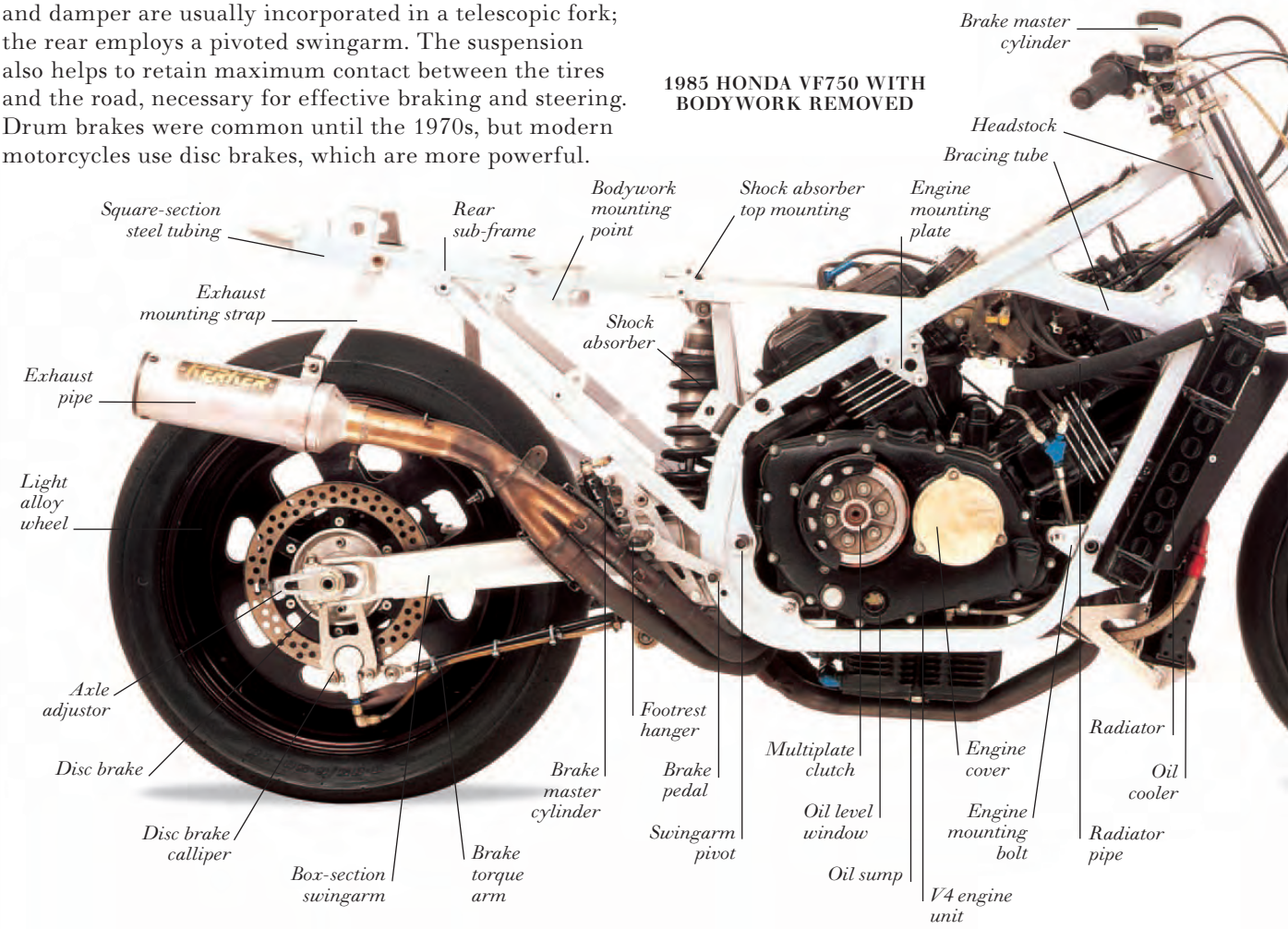
The motorcycle chassis

THE MOTORCYCLE CHASSIS is the main "body" of the motorcycle, to which the engine is attached. Consisting of the frame, wheels, suspension, and brakes, the chassis performs various functions. The frame, which is built from steel or alloy, keeps the wheels in line to maintain the handling of the motorcycle, and serves as a structure for mounting other components. The engine and gearbox unit is bolted into place, while items such as the seat, the fenders, and the fairing are more easily removable. Suspension cushions the rider from irregularities in the road surface. In most suspension systems, coil springs controlled by an oil damper separate the main mass of the motorcycle from the wheels. At the front, the spring and damper are usually incorporated in a telescopic fork; the rear employs a pivoted swingarm. The suspension also helps to retain maximum contact between the tires and the road, necessary for effective braking and steering. Drum brakes were common until the 1970s, but modern motorcycles use disc brakes, which are more powerful.

1985 HONDA VF750 WITH BODYWORK

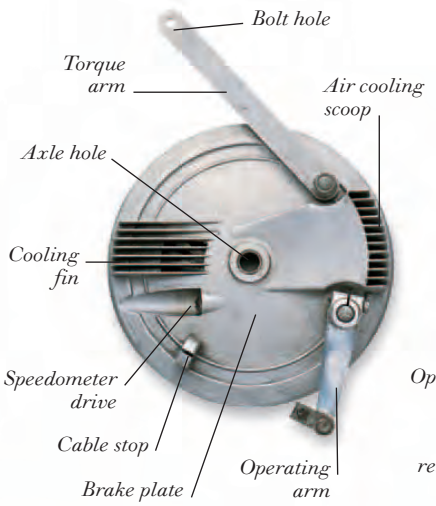


1985 HONDA VF750 WITH BODYWORK REMOVED

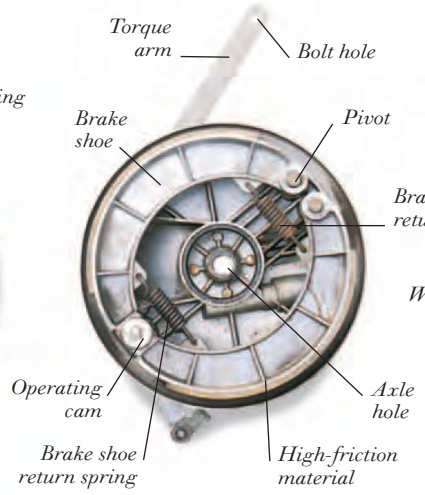


DRUM BRAKE

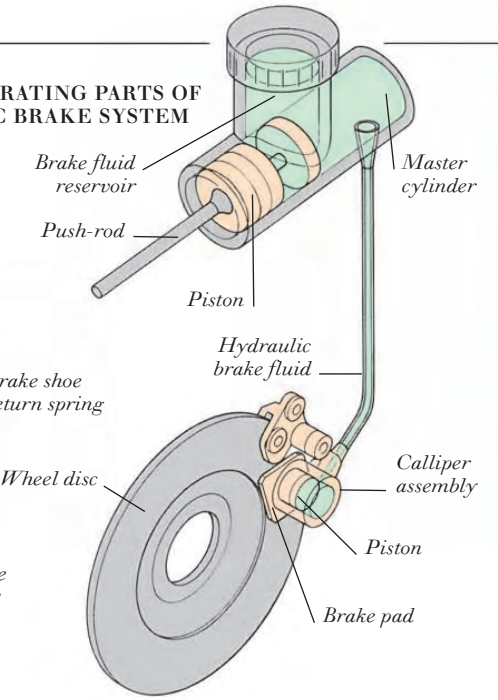
EXTERIOR OF DRUM BRAKE



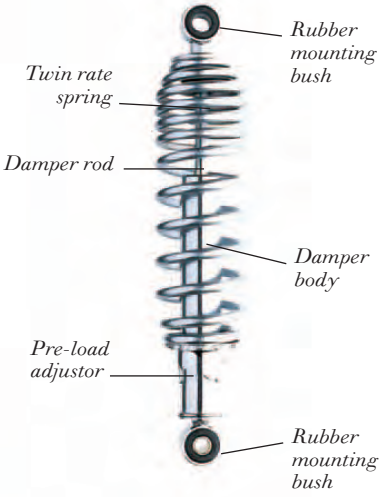
INTERIOR OF DRUM BRAKE



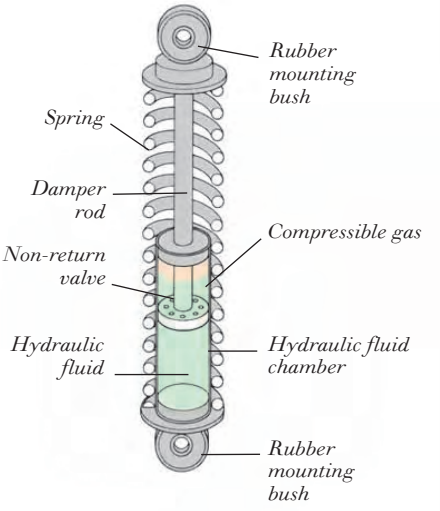
OPERATING PARTS OF DISC BRAKE SYSTEM



SPRING/DAMPER UNIT



HOW A SPRING/DAMPER UNIT WORKS



TYPES OF TIRE

RACING SLICK TIRE

TUBELESS SPORTS TIRE

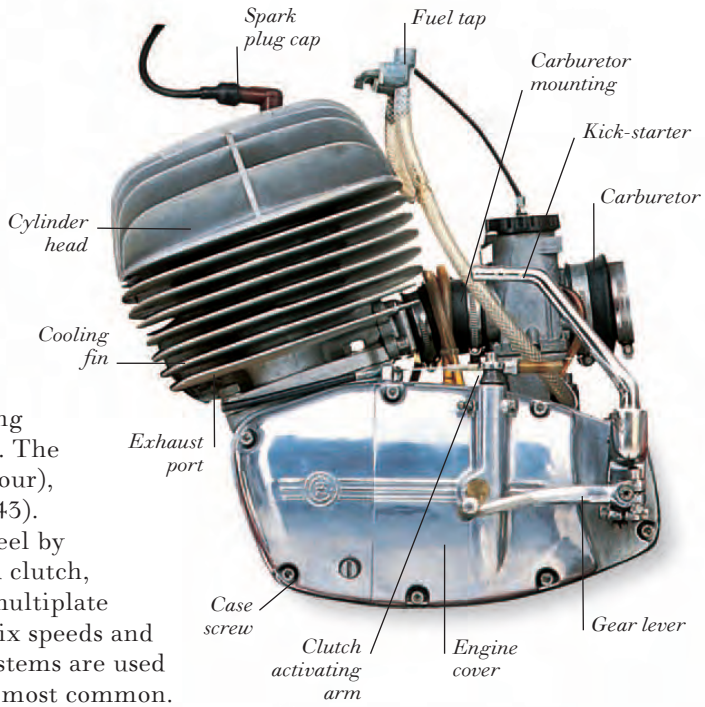
TRIALS TIRE

GENERAL-USE TIRE

Motorcycle engines

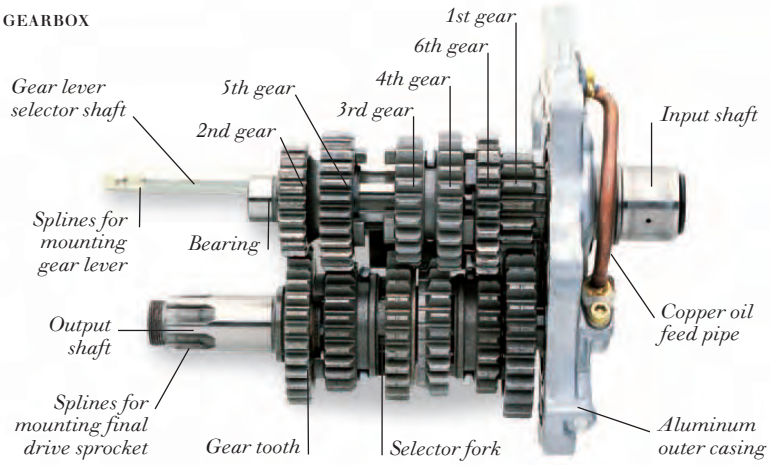
MOTORCYCLE ENGINES must be lightweight and compact and have a good power output. They have between one and six cylinders, can be cooled by air or water, and the capacity of the combustion chamber varies from 49cc (cubic centimeters) to 1500cc. Two types of internal combustion engine are common: the four-stroke, which is used in cars (see pp. 342-343), and the two-stroke. A basic two-stroke engine has only three moving parts—the crankshaft, the connecting rod, and the piston—but the power output is high. The engine fires every two strokes (rather than every four), giving a "power stroke" every revolution (see p. 343). Power is conveyed from the engine to the rear wheel by the transmission system. This usually consists of a clutch, a gearbox, and a final drive system. Clutches are multiplate devices, which run in oil. Gearboxes have five or six speeds and are operated by foot pedal. Shaft and belt drive systems are used in some cases, but chain drive to the rear wheel is most common.

EXTERIOR OF STANDARD TWO-STROKE ENGINE

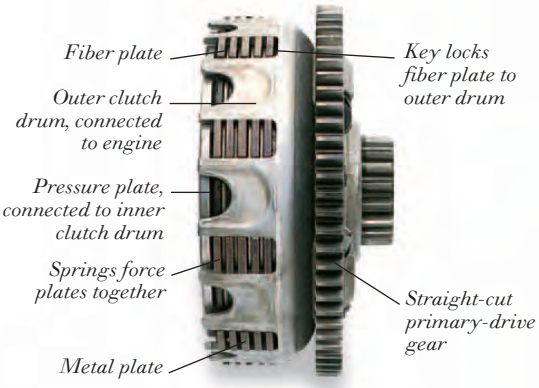


TRANSMISSION SYSTEM

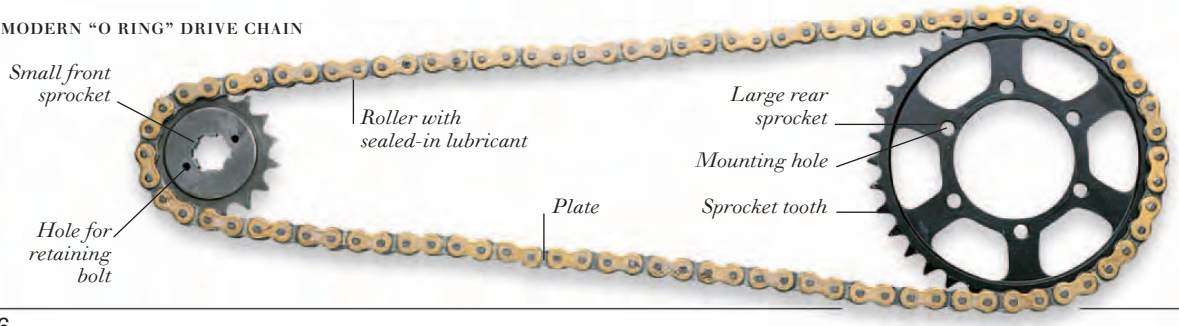
GEARBOX



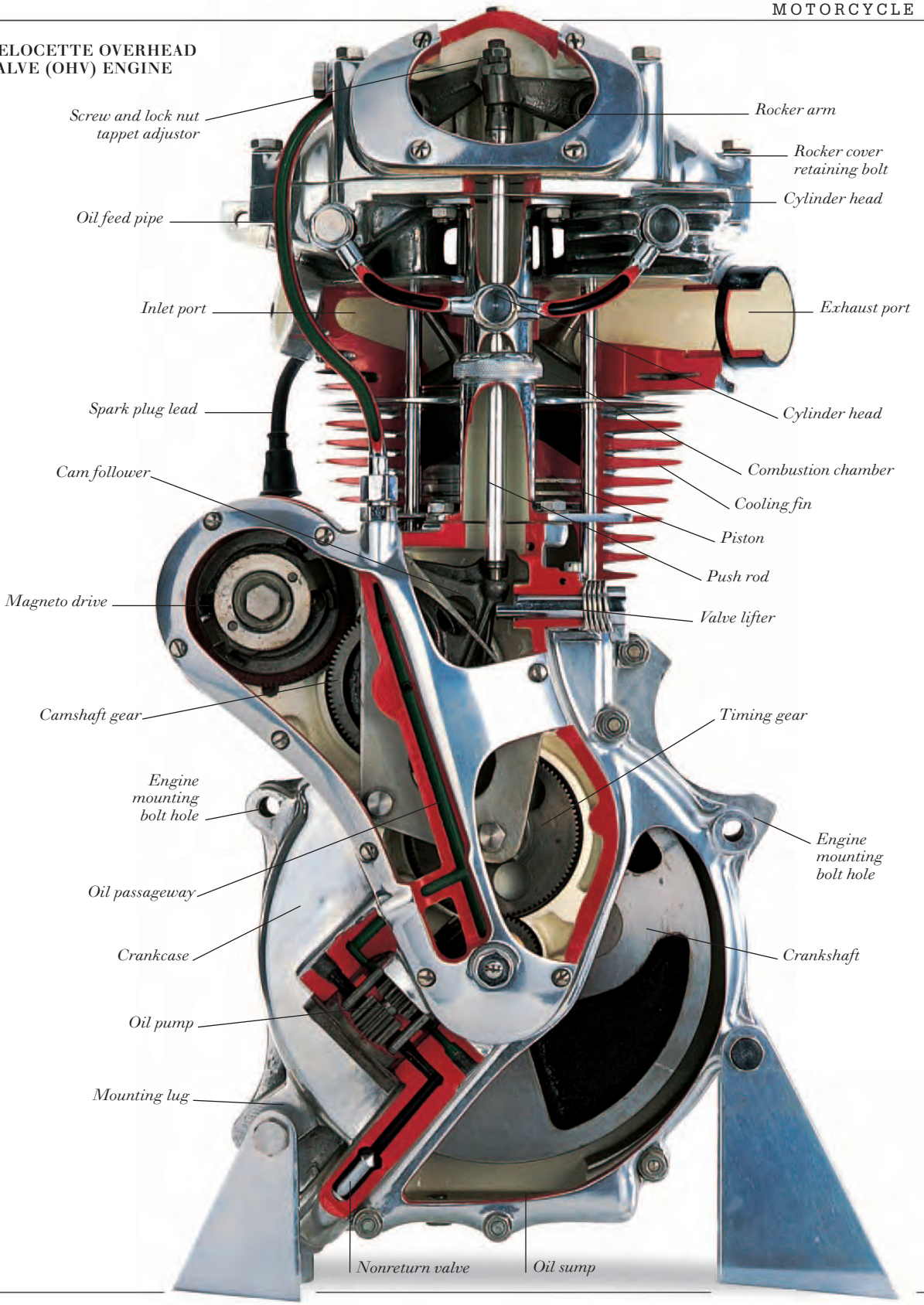
MULTIPLATE CLUTCH



MODERN "O RING" DRIVE CHAIN



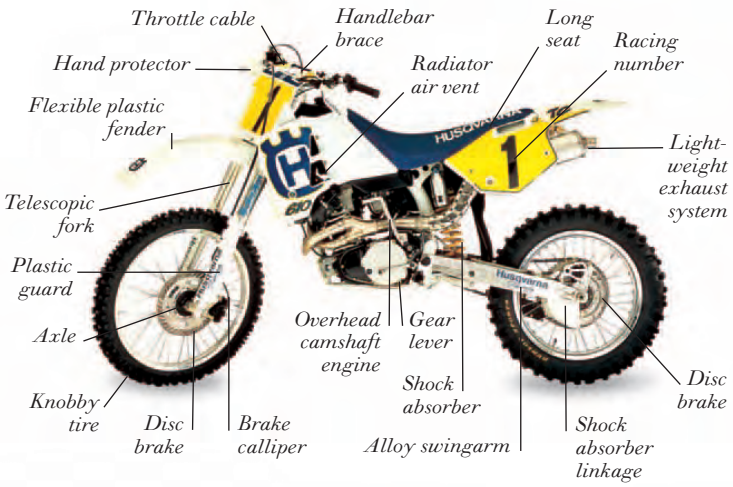
VELOCETTE OVERHEAD VALVE (OHV) ENGINE



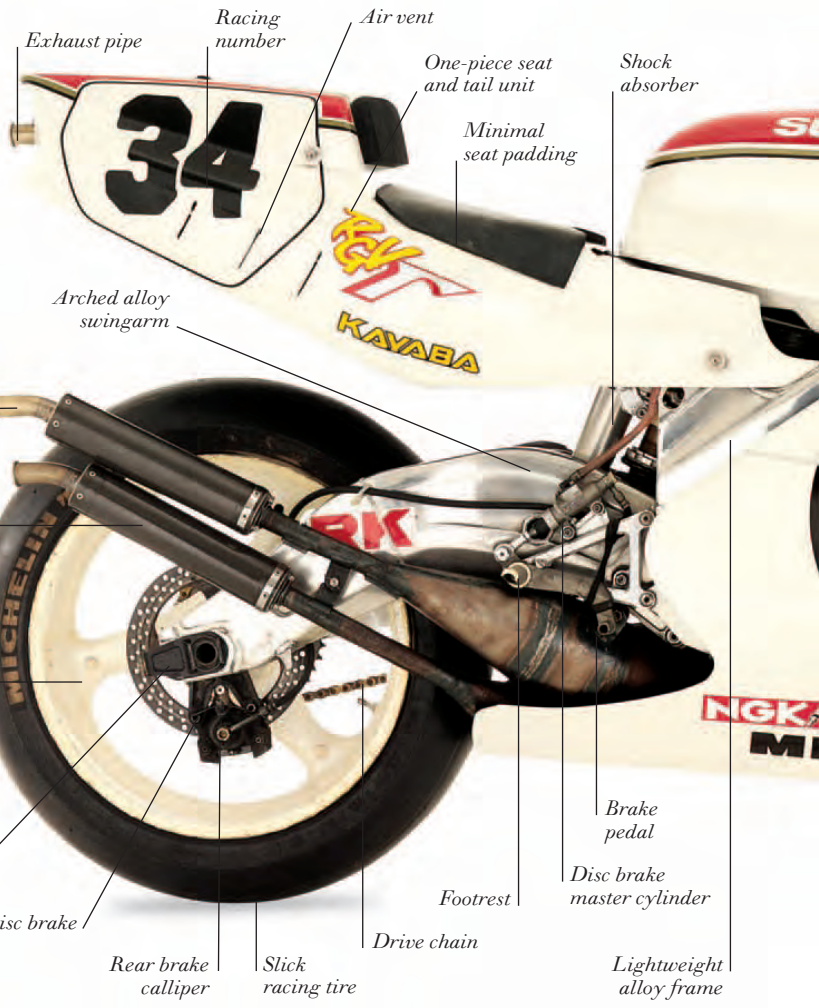
Competition motorcycles

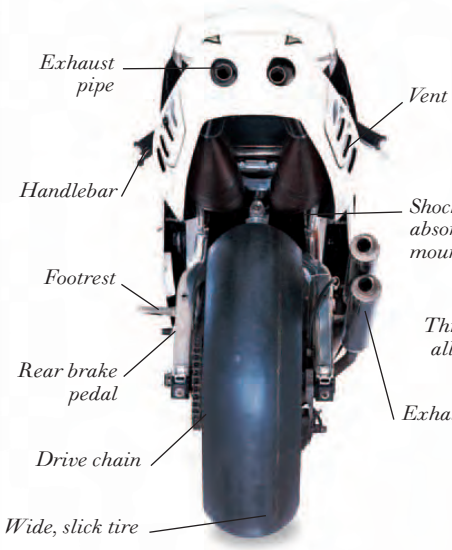
THERE ARE MANY TYPES of motorcycle sport and in each, a specialized machine has evolved to perform to specific requirements. Races take place on roads or tracks or "off-road," in fields, dirt tracks, and even the desert. "Grand Prix" world championships in road-racing are contested by three classes: 125cc, 250cc two-strokes; the top class of 500cc two-strokes; and 900cc four-stroke machines. The latest racing sidecars have more in common with racing cars than motorcycles. The rider and passenger operate within an all-enclosing, aerodynamic fairing. The Suzuki RGV500 shown here, like other Grand Prix machines, carries advertising, which helps to cover the cost of developing motorcycle technology. In Speedway, which originated in the US in 1902, motorcycles operate without brakes or a gearbox. Off-road competition motorcycles have less emphasis on high power output. In Motocross, for example, which is held on rough terrain, they must have high ground clearance, flexible long-travel suspension, and tires with a chunky tread pattern.

1992 HUSQVARNA MOTOCROSS TC610



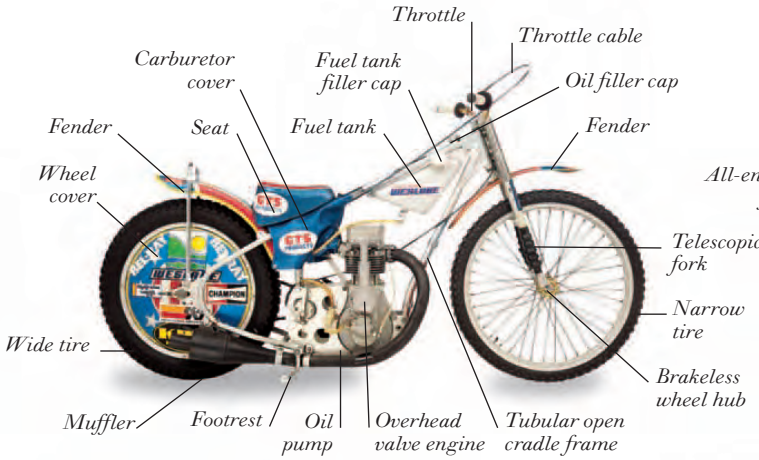
1992 SUZUKI RGV500
SIDE VIEW





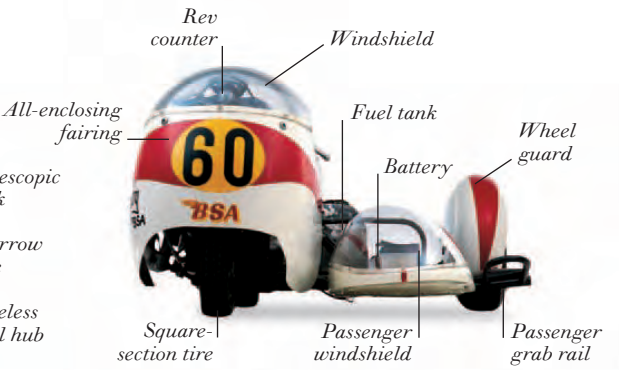
REAR VIEW

1981 WESLAKE SPEEDWAY

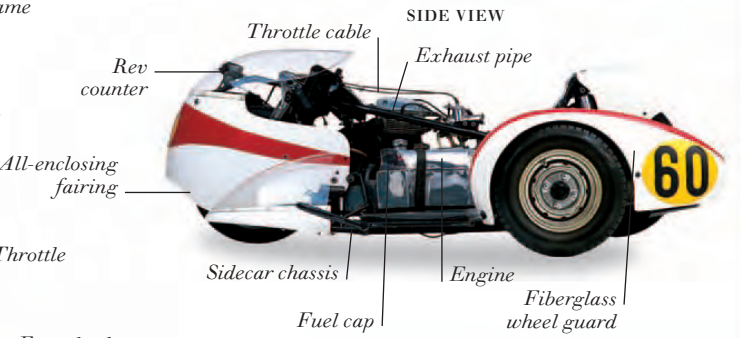


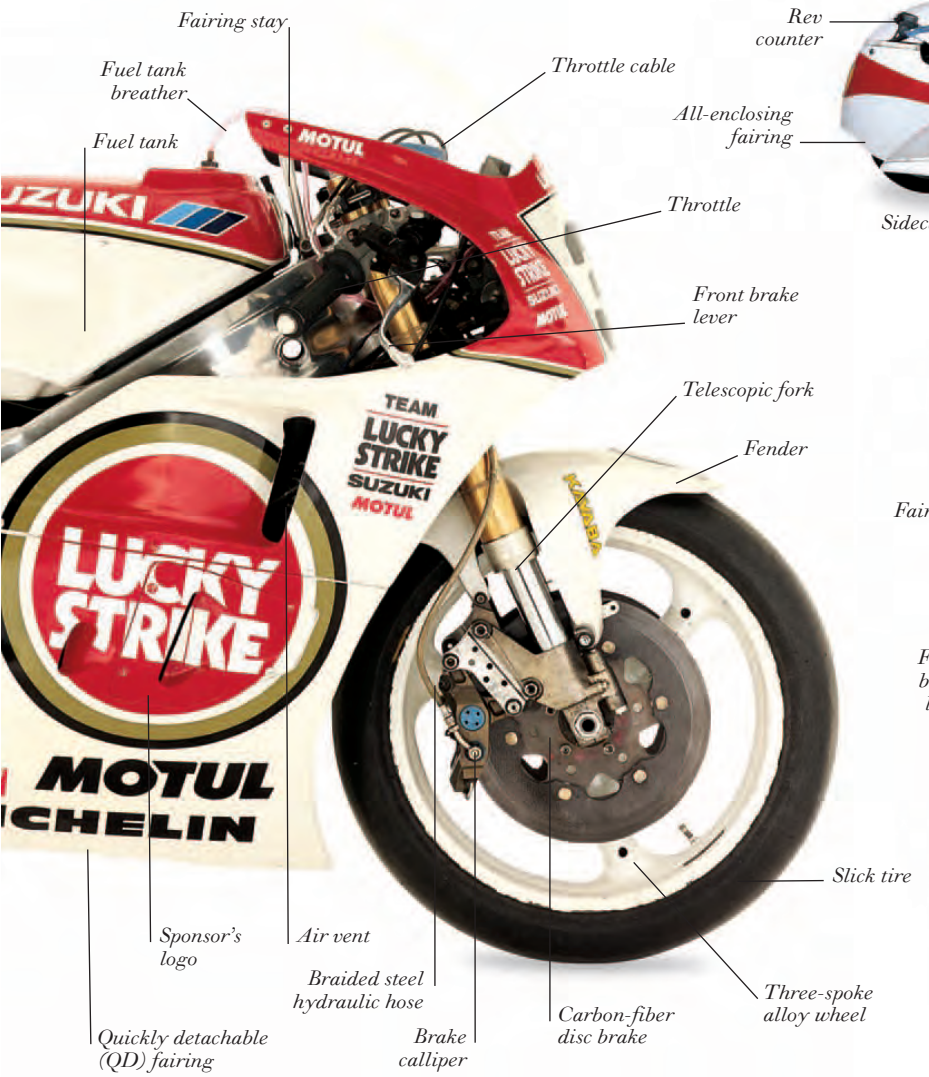
1968 KIRBY BSA RACING SIDECAR

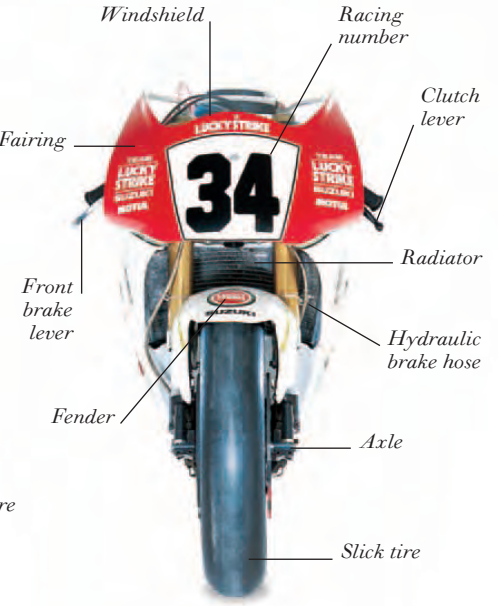
FRONT VIEW



SIDE VIEW







FRONT VIEW

Sea and Air

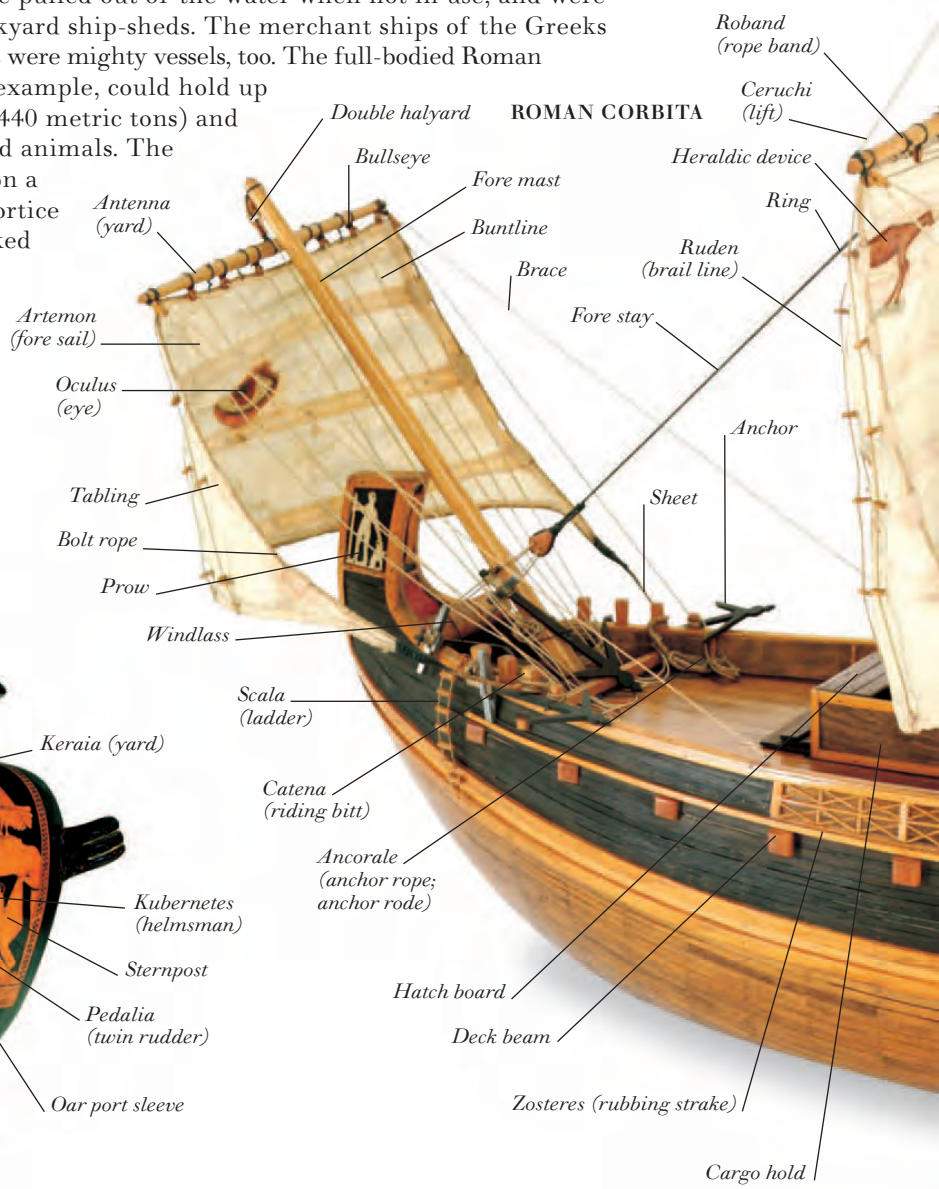
Ships of Greece and Rome 372
Viking Ships 374
Medieval Warships and Traders 376
The Expansion of Sail 378
A Ship of the Line 380
Rigging 382
Sails 384
Mooring and Anchoring 386
Ropes and Knots 388
Paddle wheels and Propellers 390
Anatomy of an Iron Ship 392
The Battleship 394
Frigates and Submarines 396
Pioneers of Flight 398
Early Monoplanes 400
Biplanes and Triplanes 402
World War I Aircraft 404
Early Passenger aircraft 406
World War II Aircraft 408
Modern Piston Aero-engines 410
Modern Jetliners 1 412
Modern Jetliners 2 414
Supersonic Jetliners 416
Jet Engines 418
Modern Military Aircraft 420
Helicopters 422
Light Aircraft 424
Gliders, Hang-gliders, and Ultralights 426

Ships of Greece and Rome

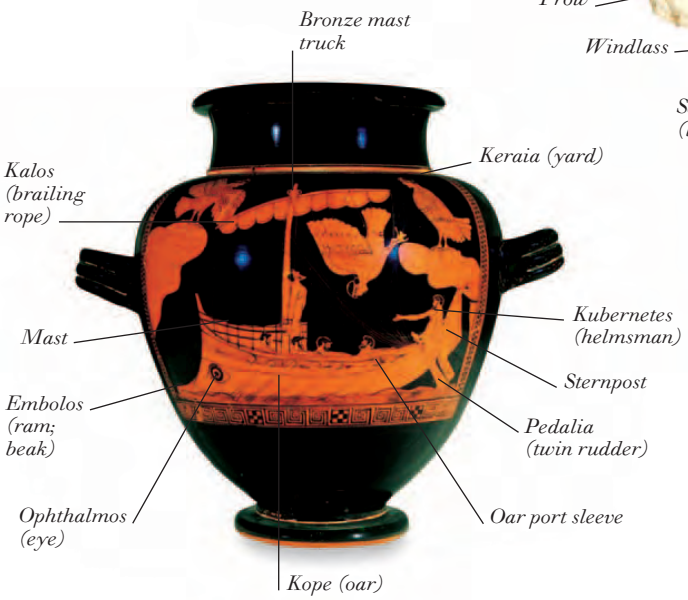
ROMAN ANCHOR

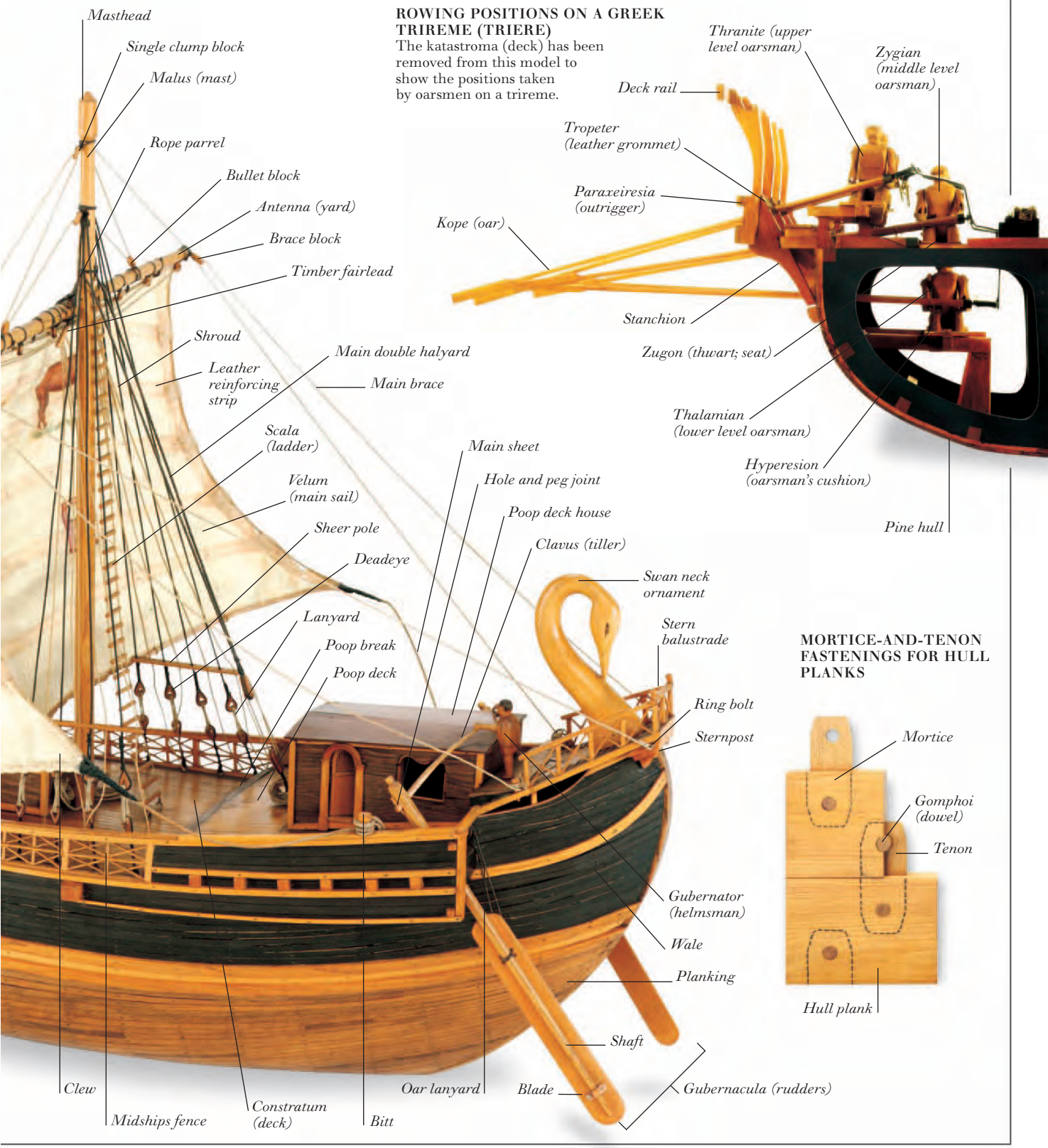
IN THE EXPANSIVE EMPIRES OF GREECE AND ROME, powerful fleets were needed for battle, trade, and communication. Greek galleys were powered by a sail and many oars. A new armament, the embolos (ram), was fitted on to the galley bow. Since ramming duels required fast and maneuverable boats, extra rows of oarsmen were added, culminating in the trireme. During the fifth and fourth centuries BC, the trireme dominated the Mediterranean. It was powered by 170 oarsmen, rowing with one oar each. The oarsmen were ranged on three levels, as the model opposite shows. The trireme also carried archers and soldiers for boarding. Galleys were pulled out of the water when not in use, and were kept in dockyard ship-sheds. The merchant ships of the Greeks and Romans were mighty vessels, too. The full-bodied Roman corbita, for example, could hold up to 400 tons (440 metric tons) and carried a cargo of spices, gems, silk, and animals. The construction of these boats was based on a stout hull with planking secured by mortice and tenon. Some of these ships embarked on long voyages, sailing even as far as India. To make them easier to steer, corbitas set a fore sail called an "artemon." It flew from a forward-leaning mast that was a forerunner of the long bowsprits carried by the great clipper ships of the 19th century.

ROMAN CORBITA



ATTIC VASE SHOWING A GALLEY



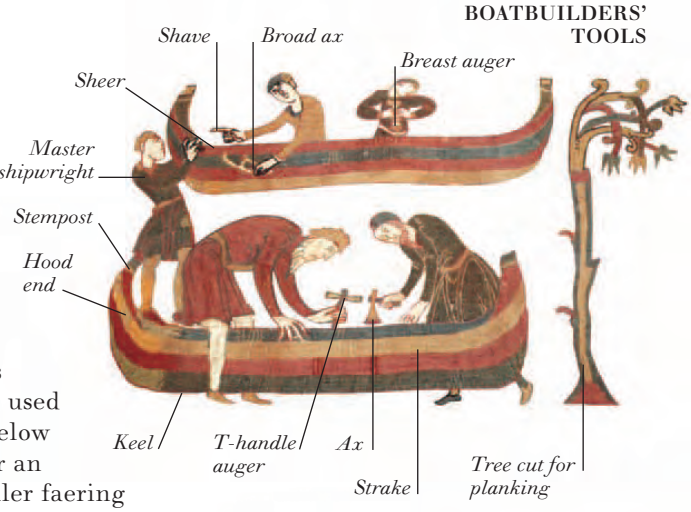


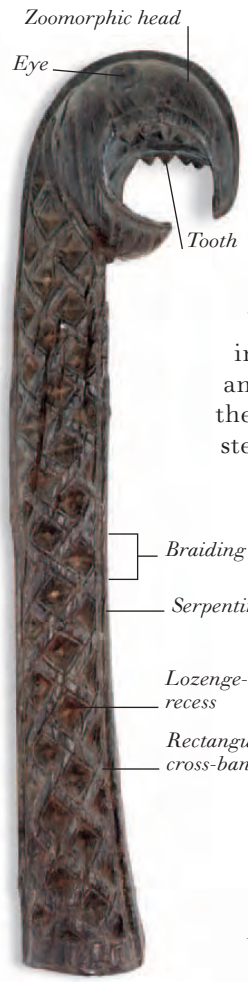
ROWING POSITIONS ON A GREEK TRIREME (TRIERE)
The katastroma (deck) has been removed from this model to show the positions taken by oarsmen on a trireme.

MORTICE-AND-TENON FASTENINGS FOR HULL PLANKS

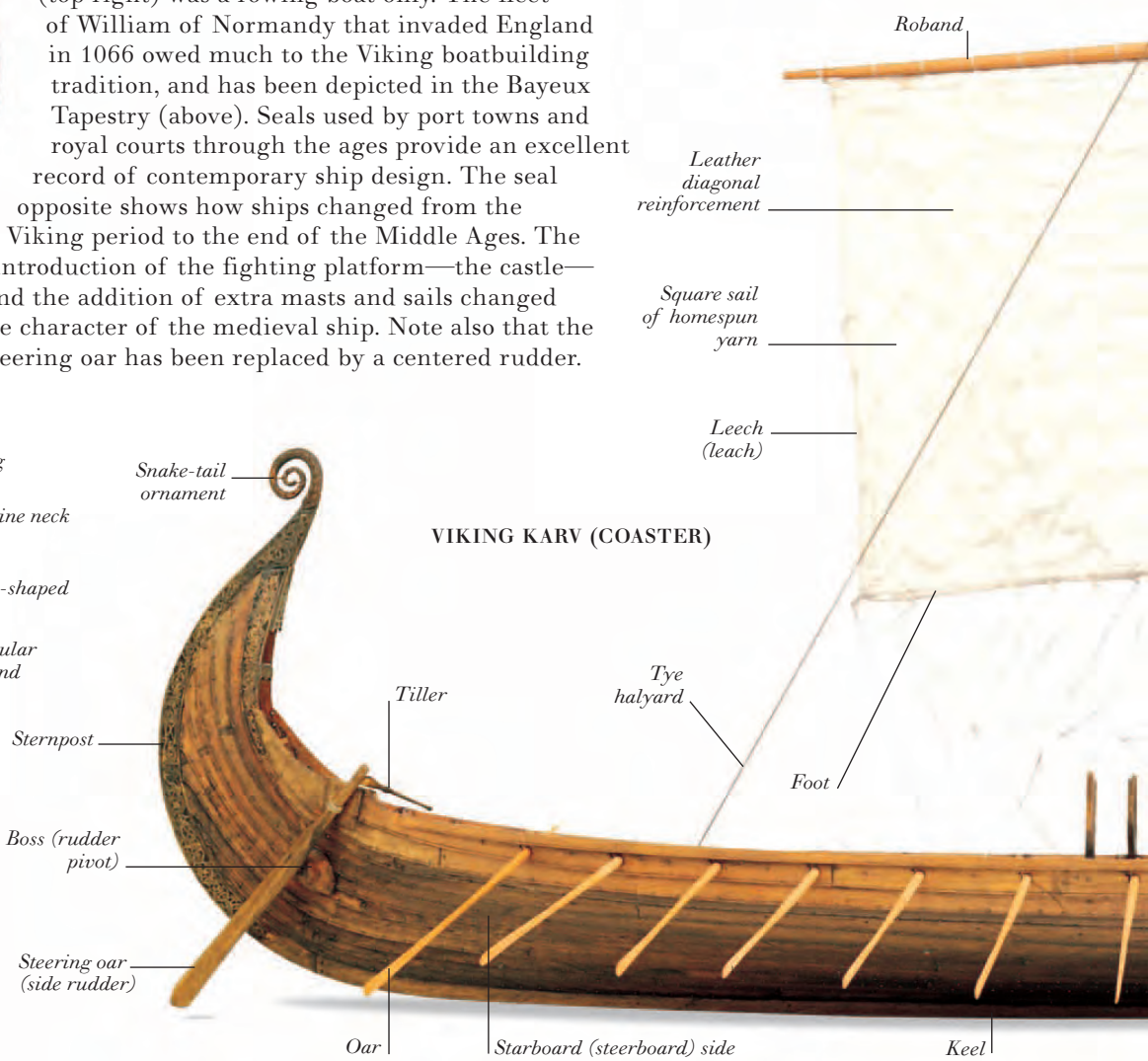
Viking ships

IN THE DARK AGES and early medieval times, the longships of Scandinavia were one of the most feared sights for people of northern Europe. The Vikings launched raids from Scandinavia every summer in longships equipped with a single steering oar on the right, or "steerboard," side (hence "starboard"). A longship had one row of oars on each side and a single sail. The hull had clinker (overlapping) planks. Prowheads adorned fighting ships during campaigns of war. The sailing longship was also used for local coastal travel. The karv below was probably built as transport for an important family, while the smaller faering (top right) was a rowing boat only. The fleet of William of Normandy that invaded England in 1066 owed much to the Viking boatbuilding tradition, and has been depicted in the Bayeux Tapestry (above). Seals used by port towns and royal courts through the ages provide an excellent record of contemporary ship design. The seal opposite shows how ships changed from the Viking period to the end of the Middle Ages. The introduction of the fighting platform—the castle—and the addition of extra masts and sails changed the character of the medieval ship. Note also that the steering oar has been replaced by a centered rudder.

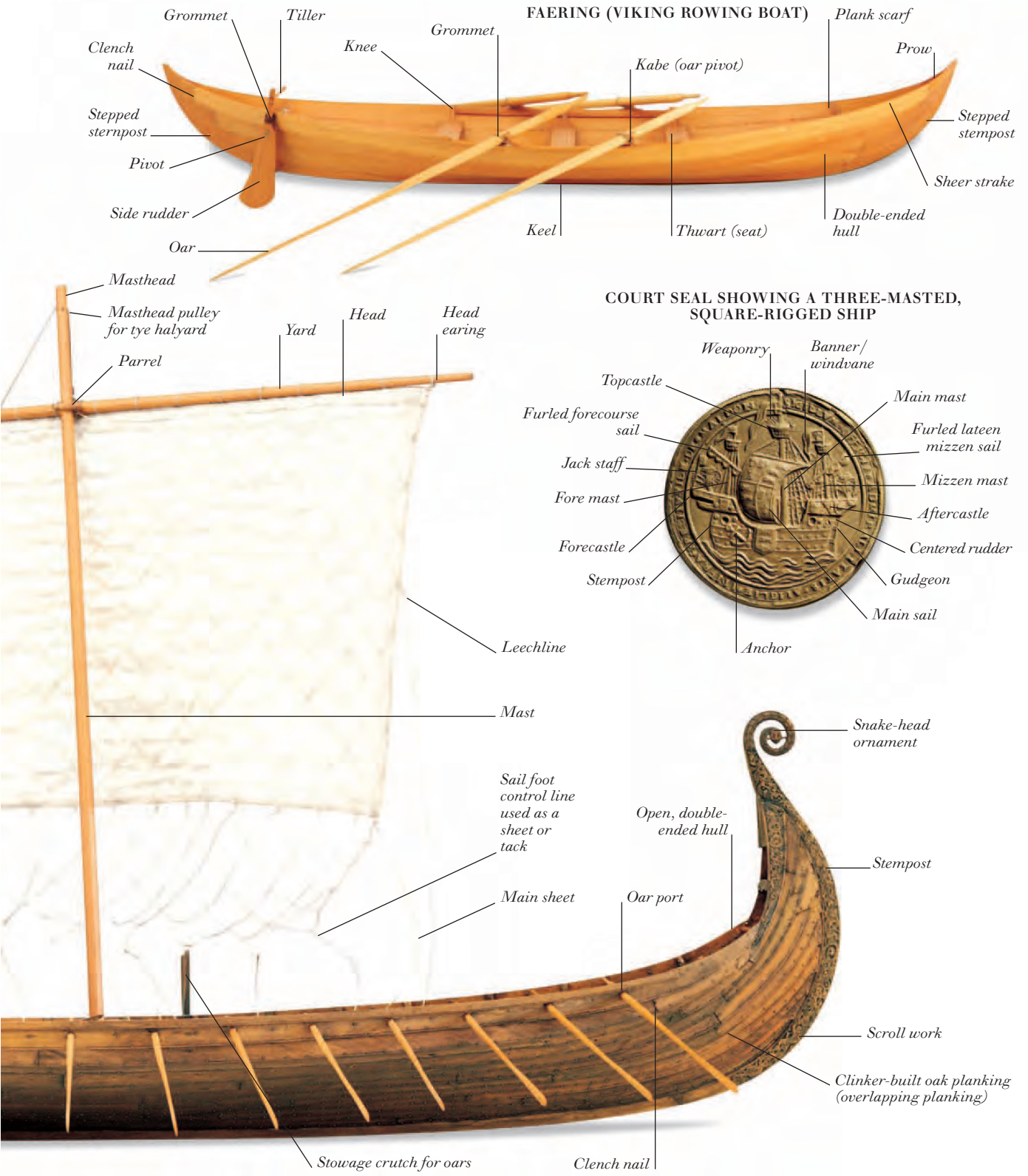




DRAGON PROWHEAD



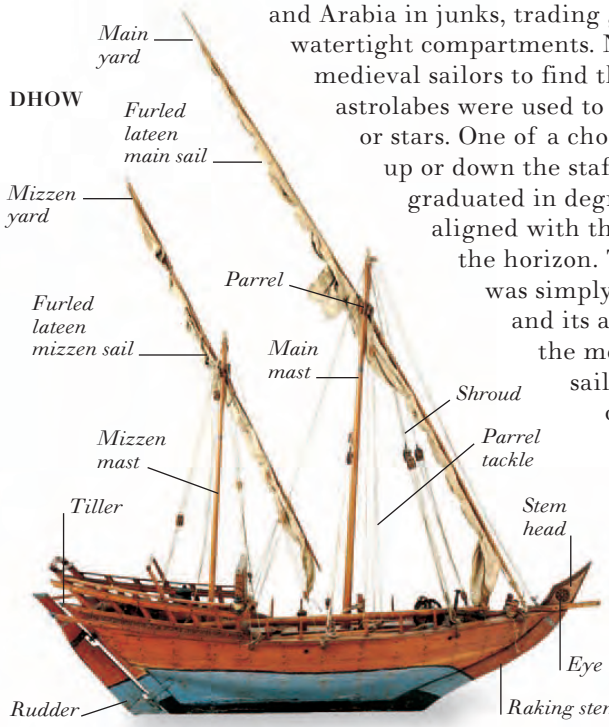
VIKING KARV (COASTER)


FAERING (VIKING ROWING BOAT)
Grommet
Tiller
Clench nail
Knee
Grommet
Kabe (oar pivot)
Plank scarf
Prow
Stepped sternpost
Pivot
Stepped stempost
Sheer strake
Side rudder
Keel
Thwart (seat)
Double-ended hull
Oar
COURT SEAL SHOWING A THREE-MASTED, SQUARE-RIGGED SHIP
Masthead
Masthead pulley for tye halyard
Yard
Head
Head earing
Parrel
Weaponry
Banner/ windvane
Topcastle
Main mast
Furled forecourse sail
Furled lateen mizzen sail
Jack staff
Mizzen mast
Fore mast
Aftercastle
Forecastle
Centered rudder
Stempost
Gudgeon
Main sail
Leechline
Anchor
Mast
Snake-head ornament
Sail foot control line used as a sheet or tack
Open, double-ended hull
Stempost
Main sheet
Oar port
Scroll work
Clinker-built oak planking (overlapping planking)
Stowage crutch for oars
Clench nail

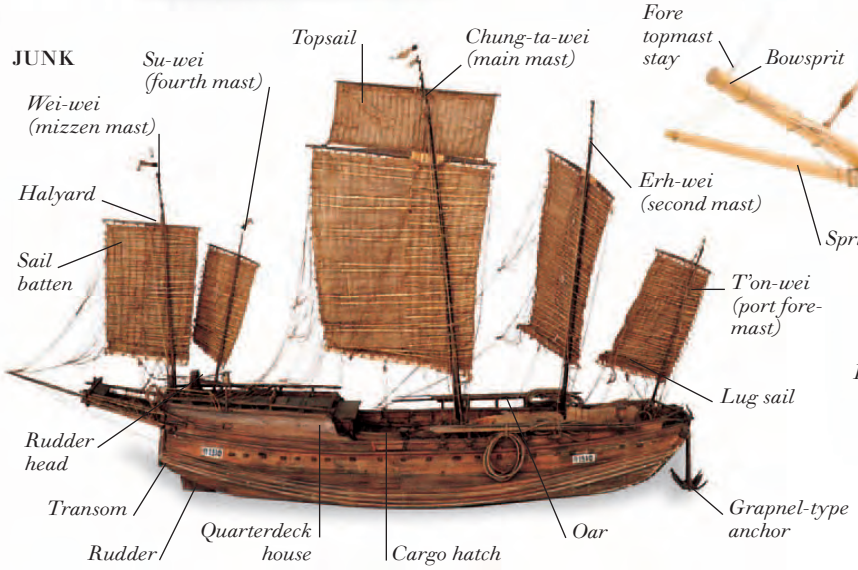
Medieval warships and traders

FROM THE 16TH CENTURY, SHIPS WERE BUILT WITH A NEW FORM OF HULL, constructed from carvel (edge-to-edge) planking. Warships of the time, like King Henry VIII of England's Mary Rose, boasted awesome fire power. This ship carried both long-range cannon in bronze, and short-range, anti personnel guns in iron. Elsewhere, ships took on a multiformity of shapes. Dhows transported slaves from East Africa to Arabia, their fore-and-aft rigged lateen sails allowing them to sail close to the wind around the lands of the Indian Ocean. The Chinese sailed to East Africa and Arabia in junks, trading goods that were carried in watertight compartments. New astronomical tools helped medieval sailors to find their way. Cross-staves and astrolabes were used to measure the altitude of the Sun or stars. One of a choice of four cross-pieces was slid up or down the staff of the cross-stave—which was graduated in degrees of altitude—until its top aligned with the celestial body and its base with the horizon. The sighting rule of the astrolabe was simply lined up with a known body, and its altitude read from marks on the metal disk. With sundials, the sailor could use the shadow of the Sun to show the time of day.

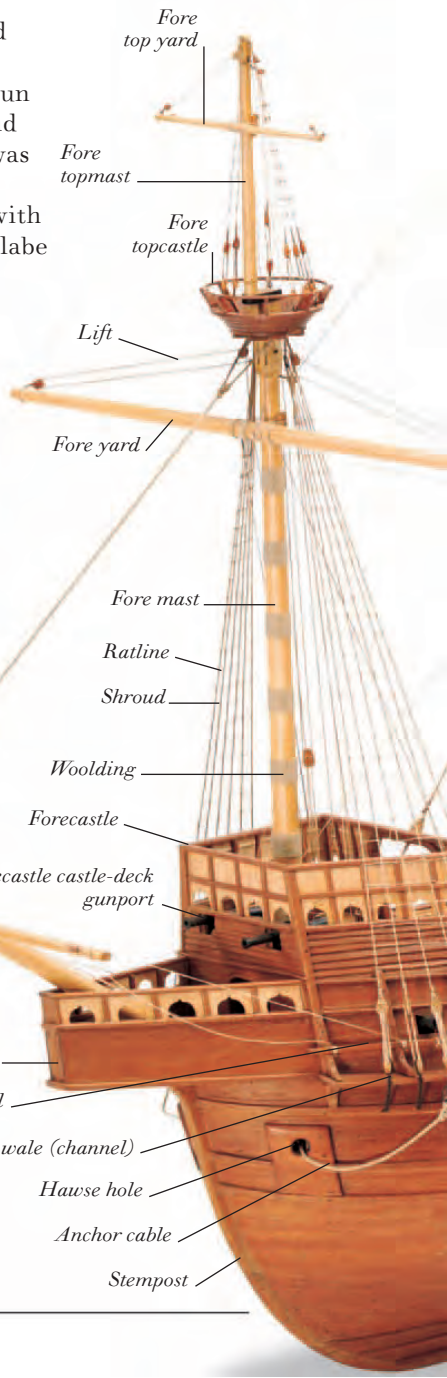
DHOW

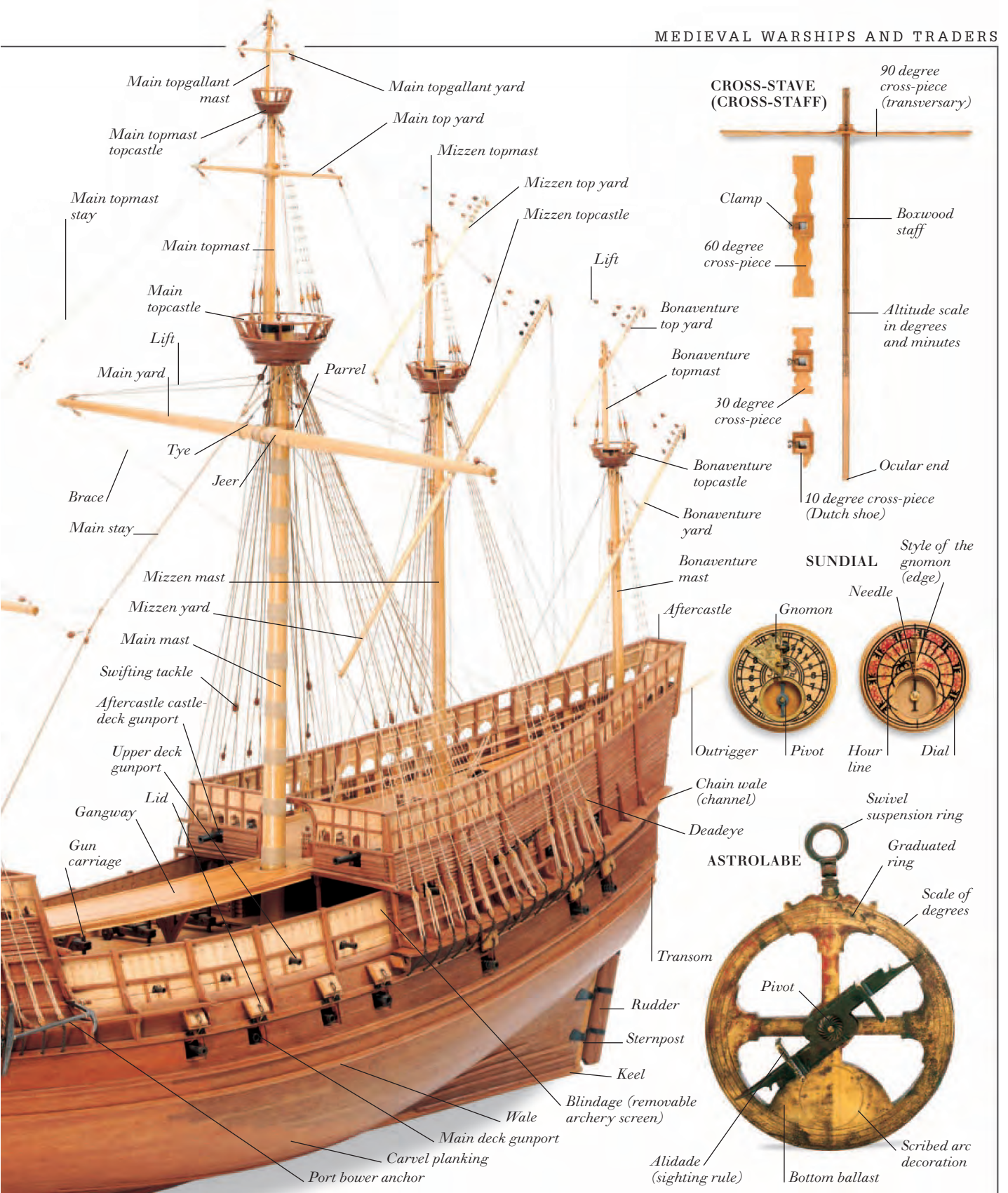


JUNK



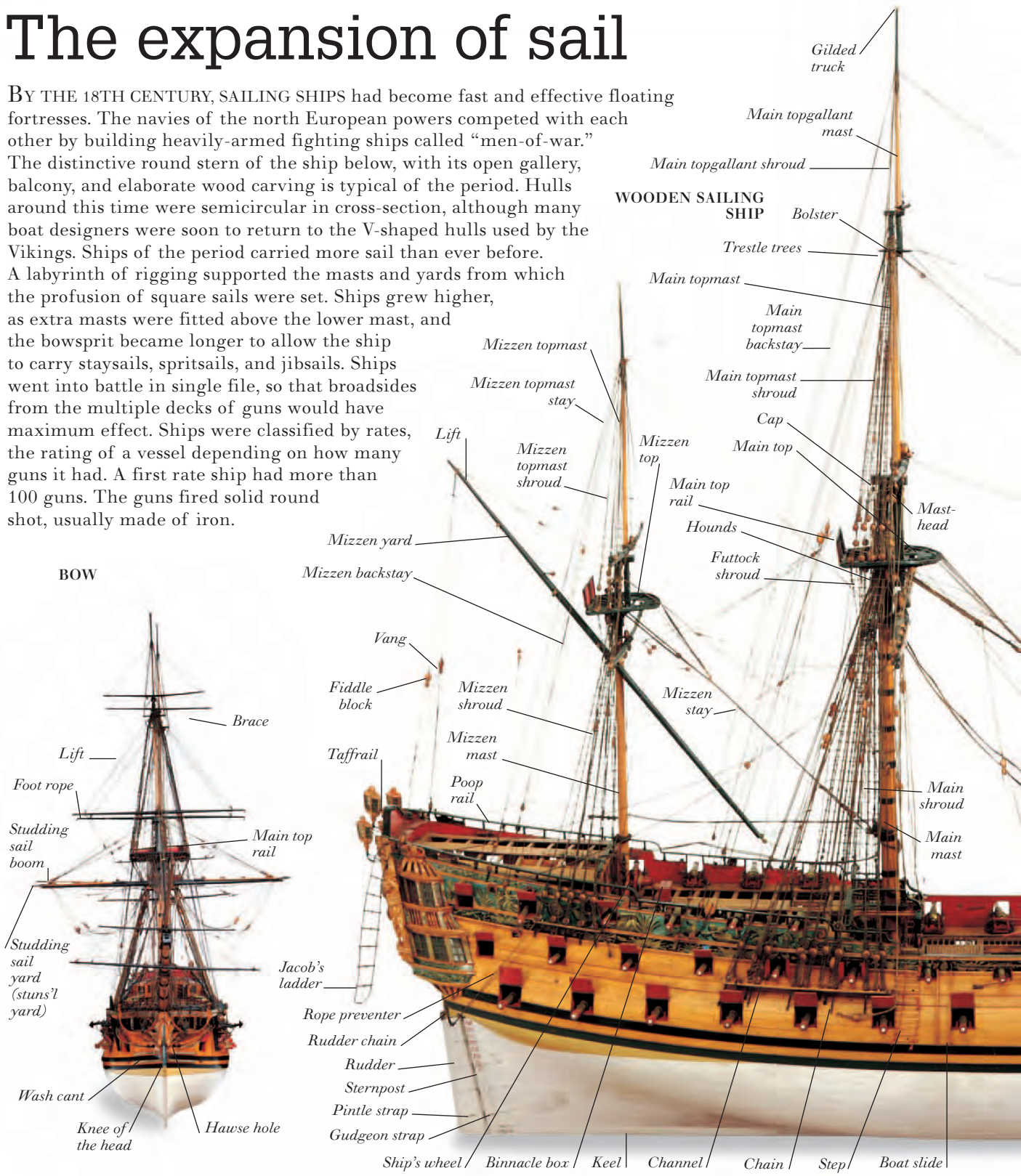
SAILING WARSHIP

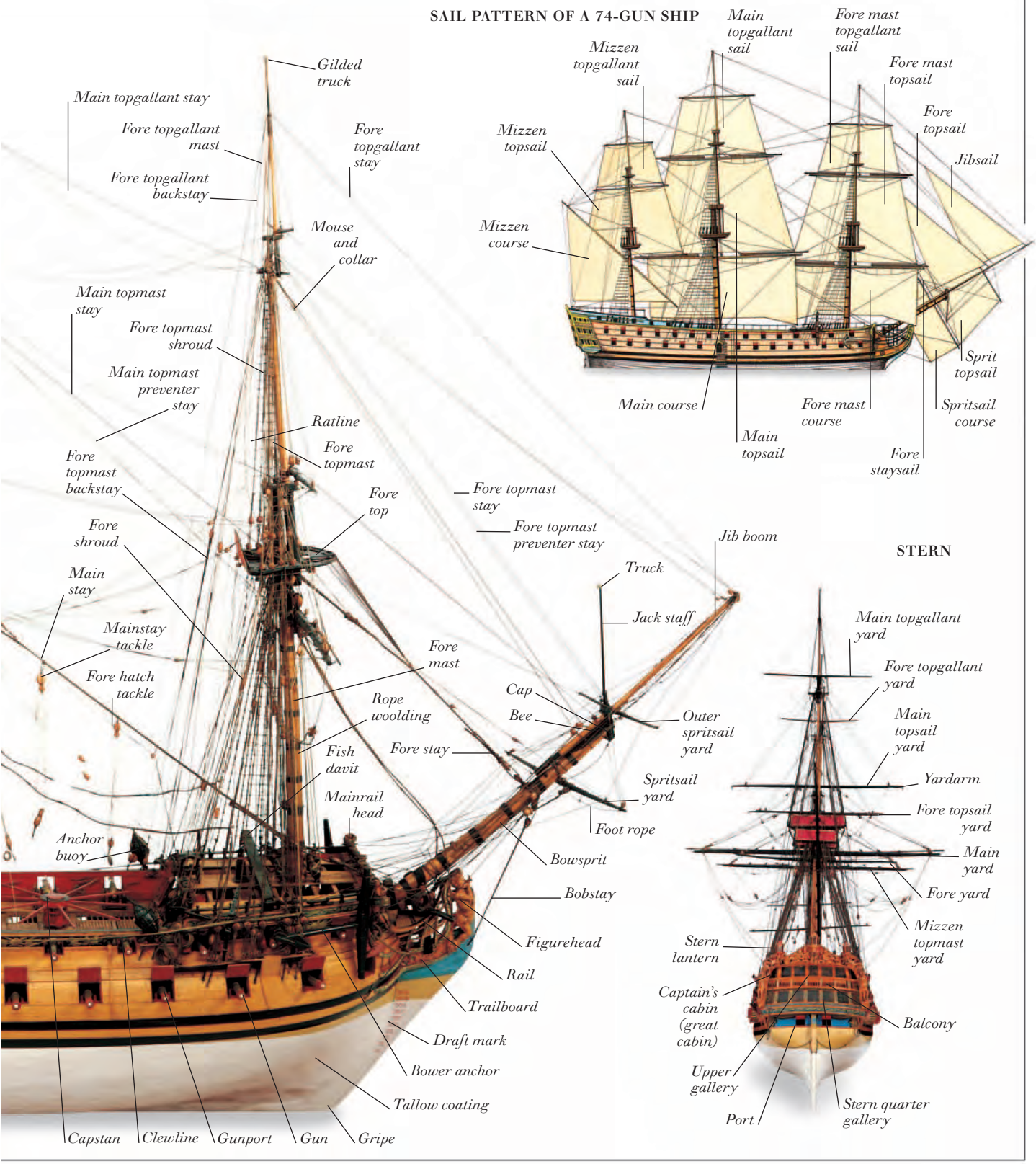



Main topgallant mast
Main topgallant yard
Main top yard
Main topmast topcastle
Mizzen topmast
Mizzen top yard
Mizzen topcastle
Main topmast stay
Main topmast
Lift
Main topcastle
Bonaventure top yard
Lift
Main yard
Parrel
Bonaventure topmast
Tye
Jeer
Bonaventure topcastle
Brace
Main stay
Bonaventure yard
Mizzen mast
Bonaventure mast
Mizzen yard
Aftercastle
Main mast
Swifting tackle
Aftercastle castle-deck gunport
Upper deck gunport
Lid
Chain wale (channel)
Gangway
Deadeye
Gun carriage
Transom
Rudder
Sternpost
Keel
Blindage (removable archery screen)
Wale
Main deck gunport
Carvel planking
Port bower anchor
CROSS-STAVE (CROSS-STAFF)
90 degree cross-piece (transversary)
Clamp
Boxwood staff
60 degree cross-piece
Altitude scale in degrees and minutes
30 degree cross-piece
Ocular end
10 degree cross-piece (Dutch shoe)
SUNDIAL
Style of the gnomon (edge)
Needle
Gnomon
Outrigger
Pivot
Hour line
Dial
ASTROLABE
Swivel suspension ring
Graduated ring
Scale of degrees
Pivot
Alidade (sighting rule)
Bottom ballast
Scribed arc decoration

The expansion of sail

BY THE 18TH CENTURY, SAILING SHIPS had become fast and effective floating fortresses. The navies of the north European powers competed with each other by building heavily-armed fighting ships called "men-of-war." The distinctive round stern of the ship below, with its open gallery, balcony, and elaborate wood carving is typical of the period. Hulls around this time were semicircular in cross-section, although many boat designers were soon to return to the V-shaped hulls used by the Vikings. Ships of the period carried more sail than ever before. A labyrinth of rigging supported the masts and yards from which the profusion of square sails were set. Ships grew higher, as extra masts were fitted above the lower mast, and the bowsprit became longer to allow the ship to carry staysails, spritsails, and jibsails. Ships went into battle in single file, so that broadsides from the multiple decks of guns would have maximum effect. Ships were classified by rates, the rating of a vessel depending on how many guns it had. A first rate ship had more than 100 guns. The guns fired solid round shot, usually made of iron.

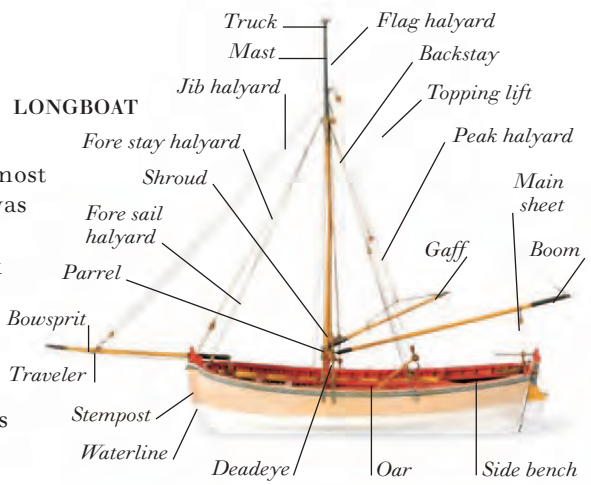



SAIL PATTERN OF A 74-GUN SHIP
Main topgallant sail
Fore mast topgallant sail
Mizzen topgallant sail
Fore mast topsail
Fore topsail
Jibsail
Mizzen topsail
Mizzen course
Sprit topsail
Main course
Fore mast course
Spritsail course
Main topsail
Fore staysail
Gilded truck
Main topgallant stay
Fore topgallant mast
Fore topgallant stay
Fore topgallant backstay
Mouse and collar
Main topmast stay
Fore topmast shroud
Main topmast preventer stay
Ratline
Fore topmast
Fore topmast backstay
Fore top
Fore topmast stay
Fore topmast preventer stay
Jib boom
Fore shroud
Main stay
Truck
Jack staff
Mainstay tackle
Fore hatch tackle
Fore mast
Cap
Bee
Outer spritsail yard
Rope woolding
Fish davit
Fore stay
Spritsail yard
Mainrail head
Foot rope
Anchor buoy
Bowsprit
Bobstay
Figurehead
Rail
Trailboard
Draft mark
Bower anchor
Tallow coating
Capstan
Clewline
Gunport
Gun
Gripe
STERN
Main topgallant yard
Fore topgallant yard
Main topsail yard
Yardarm
Fore topsail yard
Main yard
Fore yard
Mizzen topmast yard
Stern lantern
Captain's cabin (great cabin)
Balcony
Upper gallery
Port
Stern quarter gallery

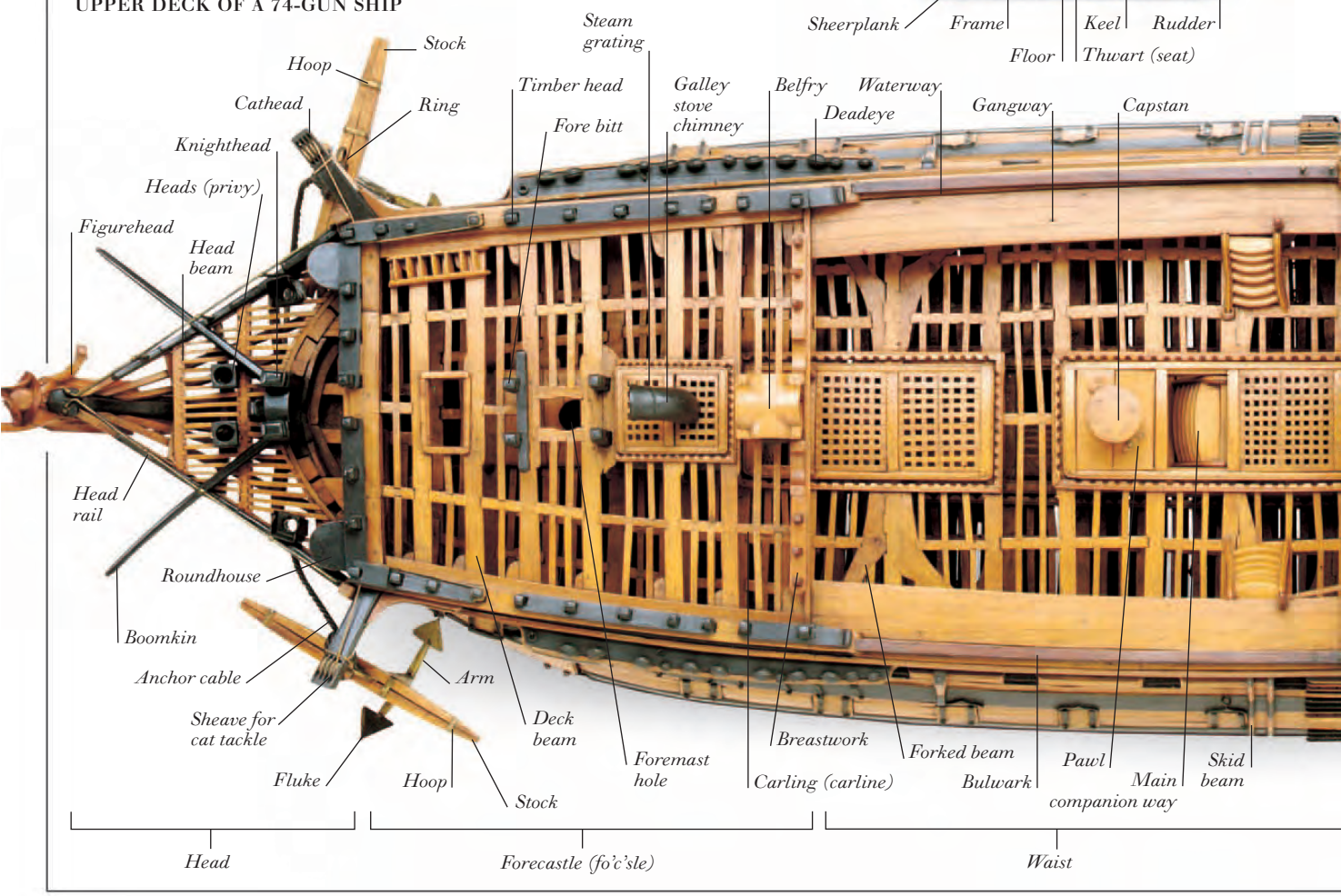
A ship of the line

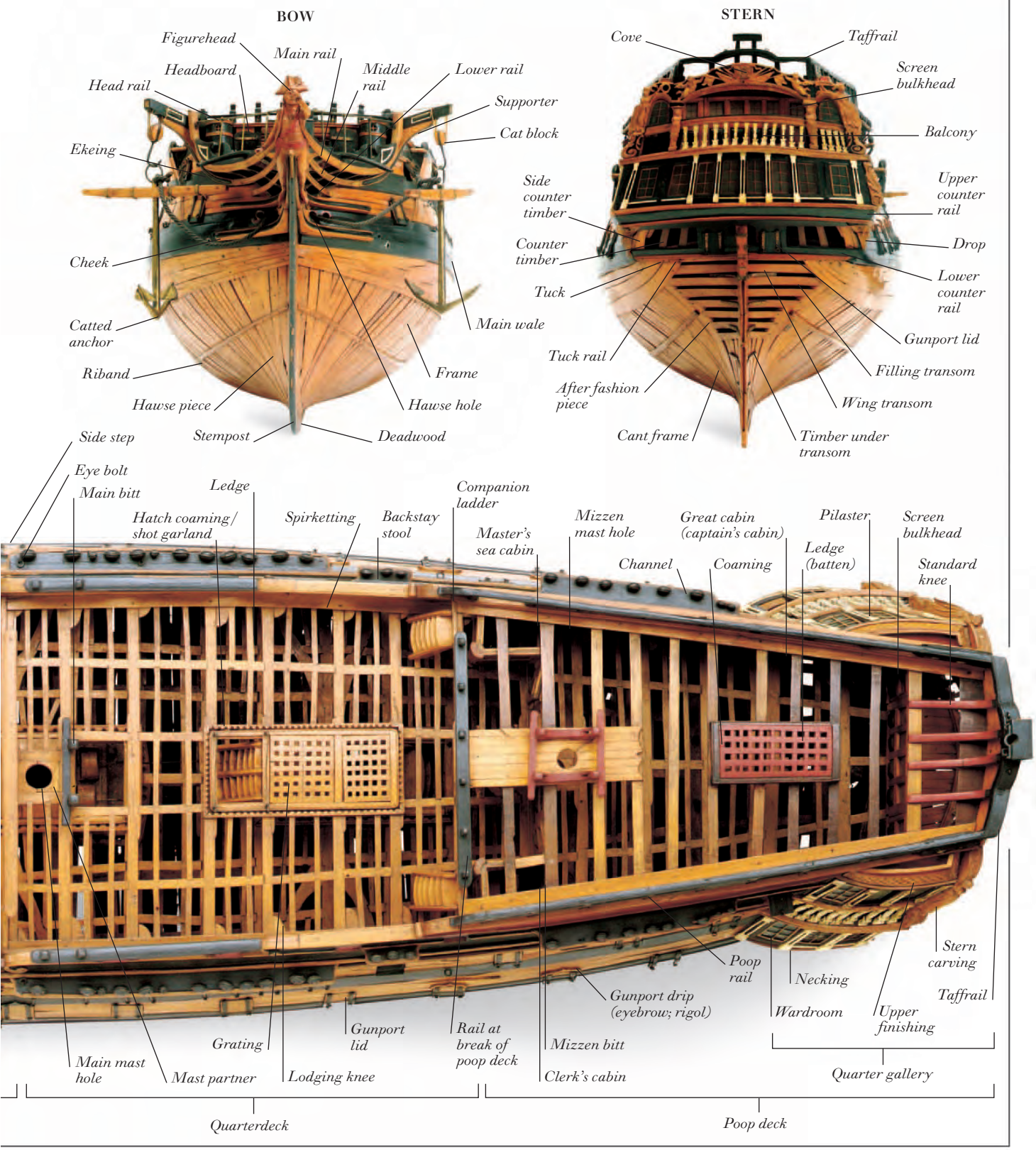
THE 74-GUN WOODEN SHIP WAS A MAINSTAY of British and French battlefleets in the late 18th and early 19th centuries. This "ship of the line" was heavy enough to fight with the most potent of rivals, yet nimble, too. The length of such a ship was determined by the number of guns required for each deck, allowing enough room for crews to man them. The gun deck was about 170 ft (52 m) long. The decks had to be very strong to carry the weight of the guns. The deck planks have been removed on the vessel pictured below, to show just how close together the beams had to be to make the hull strong enough. Only timber with a perfect grain was used. The upper deck was open at the waist, but afore and abaft were officers' cabins. The forecastle and quarterdeck carried light guns and acted as platforms for working rigging and for reconnaissance. The ship's longboats (launches) were carried on booms between the gangways.

LONGBOAT



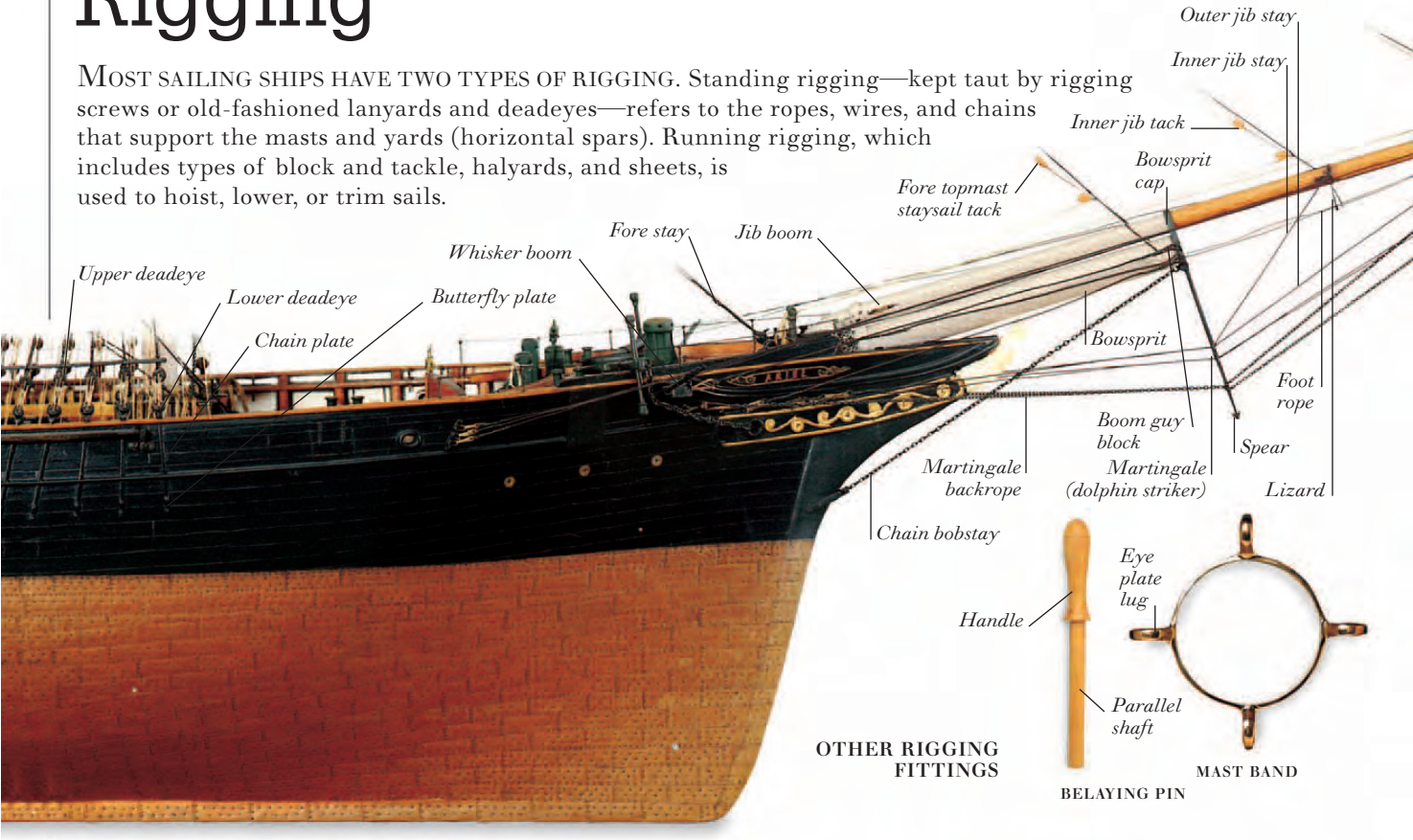
UPPER DECK OF A 74-GUN SHIP

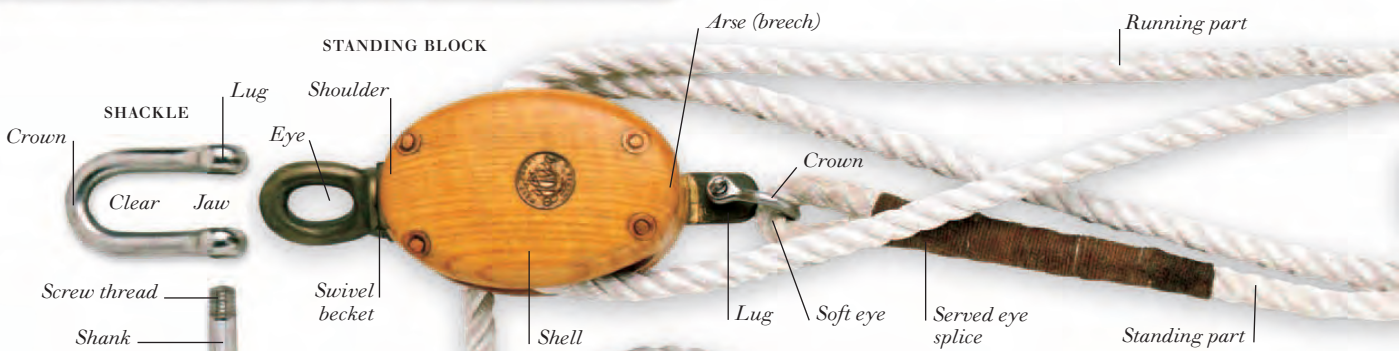


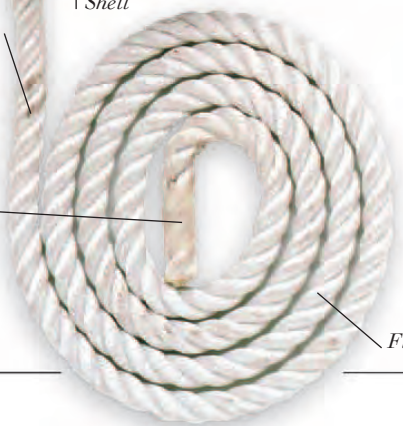

BOW
Figurehead
Main rail
Headboard
Middle rail
Lower rail
Head rail
Supporter
Cat block
Ekeing
Cheek
Catted anchor
Main wale
Riband
Frame
Hawse piece
Hawse hole
Stempost
Deadwood
STERN
Cove
Taffrail
Screen bulkhead
Balcony
Upper counter rail
Side counter timber
Drop
Counter timber
Lower counter rail
Tuck
Gunport lid
Tuck rail
Filling transom
After fashion piece
Wing transom
Cant frame
Timber under transom
Side step
Eye bolt
Main bitt
Ledge
Companion ladder
Hatch coaming/ shot garland
Spirketting
Backstay stool
Master's sea cabin
Mizzen mast hole
Great cabin (captain's cabin)
Pilaster
Screen bulkhead
Channel
Coaming
Ledge (batten)
Standard knee
Stern carving
Poop rail
Necking
Taffrail
Gunport drip (eyebrow; rigol)
Wardroom
Upper finishing
Grating
Gunport lid
Rail at break of poop deck
Mizzen bitt
Main mast hole
Mast partner
Lodging knee
Clerk's cabin
Quarter gallery
Quarterdeck
Poop deck

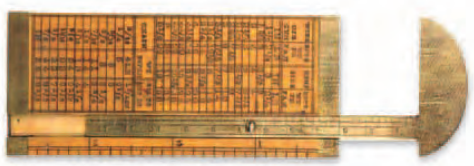
Rigging

MOST SAILING SHIPS HAVE TWO TYPES OF RIGGING. Standing rigging—kept taut by rigging screws or old-fashioned lanyards and deadeyes—refers to the ropes, wires, and chains that support the masts and yards (horizontal spars). Running rigging, which includes types of block and tackle, halyards, and sheets, is used to hoist, lower, or trim sails.







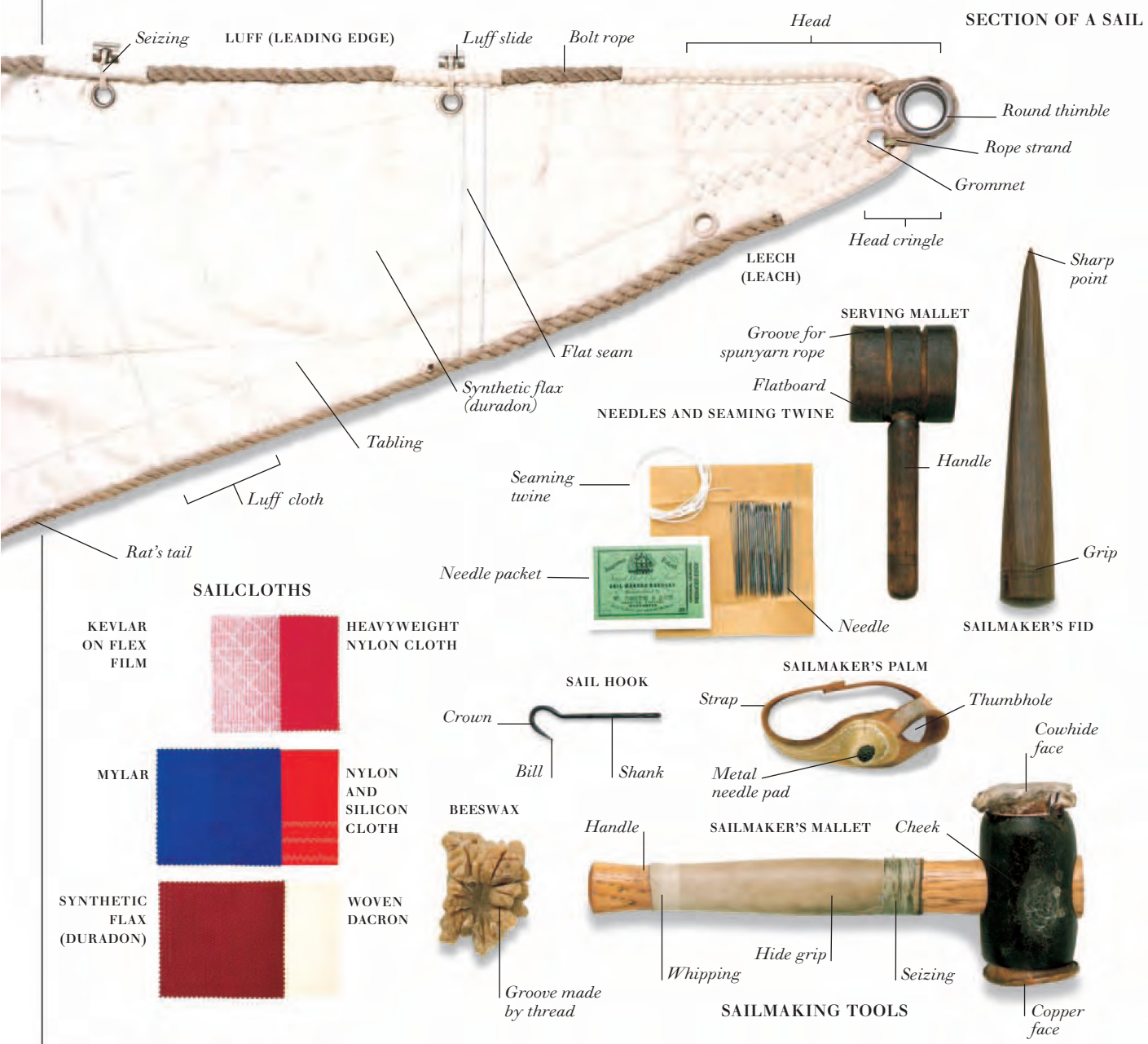


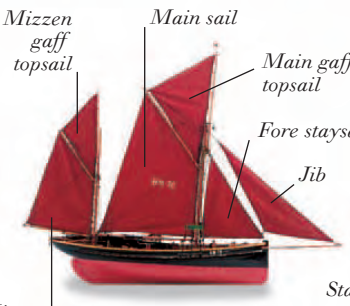
Fore royal stay
Flying jib tack
Outer jib tack
Outer martingale stay
Middle martingale stay
Inner martingale stay
Double rope becket
DUTCH TRIPLE FIDDLE BLOCK
Flat seizing
Swallow
Strop
Sheave
Eye
SCORED BULLSEYE FAIRLEAD
Eye
Strap
SHEET LEAD
Base
RUNNING BLOCK
Shoulder
Back
Shank
HOOK
Crown
Clear
Jaw
Fixed lug
Bill
Cheek
Pin cover
SPLICING FID
ROPE SERVING MALLET
HEAVER FOR WIRE SERVING
PRICKERS
HOLLOW SPIKE FOR WIRE
MARLINSPIKE
LANYARD AND DEADEYES
RIGGING SCREW (TURNBUCKLE)
Leather pointing
Shroud
Spun yarn serving
Turk's head
Flat wire seizing
Hitched hauling end
UPPER DEADEYE
Solid heart thimble
Cotter pin
Swallow
Fork end
Tail
Standing part
Right hand screw
LANYARD
Open body
Left hand screw
Safe working load mark
LOWER DEADEYE
Seizing
Swallow
Grooving
Shoulder
Binding
Face
Bolt
Eye
Nut
Crown

PARREL BEADS

Sails

THERE ARE TWO MAIN TYPES OF SAIL, often used in combination. Square sails are driving sails. They are usually attached by parrels to yards, square to the mast to catch the following wind. On fore-and-aft sails, such as lateen and lug sails, the luff (leading edge) usually abuts a mast or a stay. The head of the sail may abut a gaff, and the foot a boom. Around the world, a great range of rigs (sail patterns), such as the ketch, lugger, and schooner, have evolved to suit local needs. Sails are made from strips of cloth, cut to give the sail a belly and strong enough to resist the most violent of winds. Cotton and flax are the traditional sail materials, but synthetic fabrics are now commonly used.

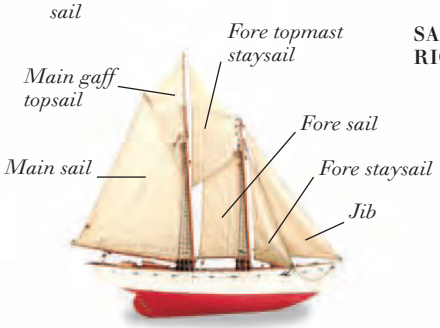




KETCH

LUGGER

SAILING RIGS



FISHERMAN'S SCHOONER
(FORE-AND-AFT SCHOONER)

SAILS AND RUNNING RIGGING OF A DOUBLE TOPSAIL SCHOONER

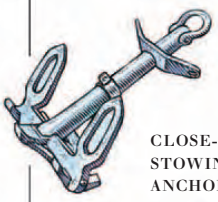
Upper topsail lift
Lower topsail brace
Main topsail halyard
Triatic stay
Flying jib halyard
Fore upper topsail
Foot rope
Upper topsail brace
Outer jib halyard
Fore peak halyard
Lower topsail clewline
Fore yard lift
Fore lower topsail
Inner jib halyard
Fore throat halyard
Fore staysail halyard
Fore sail
Mast hoop
Inner jib downhaul
Outer jib downhaul
Outer jib sheet
Flying jib sheet
Inner jib sheet
Flying jib downhaul
Yard
Gaff
Head
Luff
Boom
Foot
Flying jib
Outer jib
Reef point
Inner jib
Fore staysail
Fore staysail sheet

Mooring and anchoring

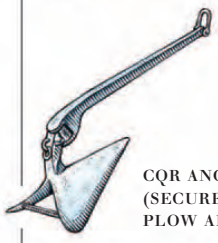
FOR LARGE VESSELS IN OPEN WATER, ANCHORAGE IS ESSENTIAL. By holding a ship securely to the seabed, an anchor prevents the vessel from being at the mercy of wave, tide, and current. The earliest anchors were nothing more than stones. In later years, many anchors had a standard design, much like the Admiralty pattern anchor shown on this page. The Danforth anchor is somewhat different. It has particularly deep flukes to give it great holding power. On large sailing ships, anchors were worked by teams of sailors. They turned the drum of a capstan by pushing on bars slotted into the revolving cylinder. This, in turn, lifted or lowered the anchor chain. In calm harbors and estuaries, ships can moor (make fast) without using anchors. Berthing ropes can be attached to bollards both inboard and on the quayside. Berthing ropes are joined to each other by bends, like those opposite.

STONE ANCHOR (KILLICK)

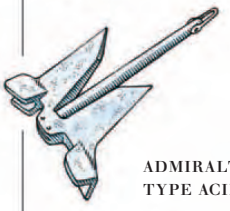
TYPES OF ANCHOR



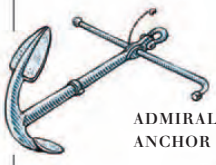
CLOSE-STOWING ANCHOR



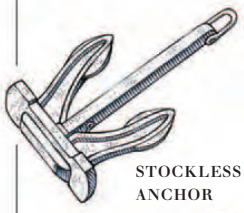
CQR ANCHOR (SECURE ANCHOR; PLOW ANCHOR)



ADMIRALTY ANCHOR TYPE ACII



ADMIRALTY PATTERN ANCHOR



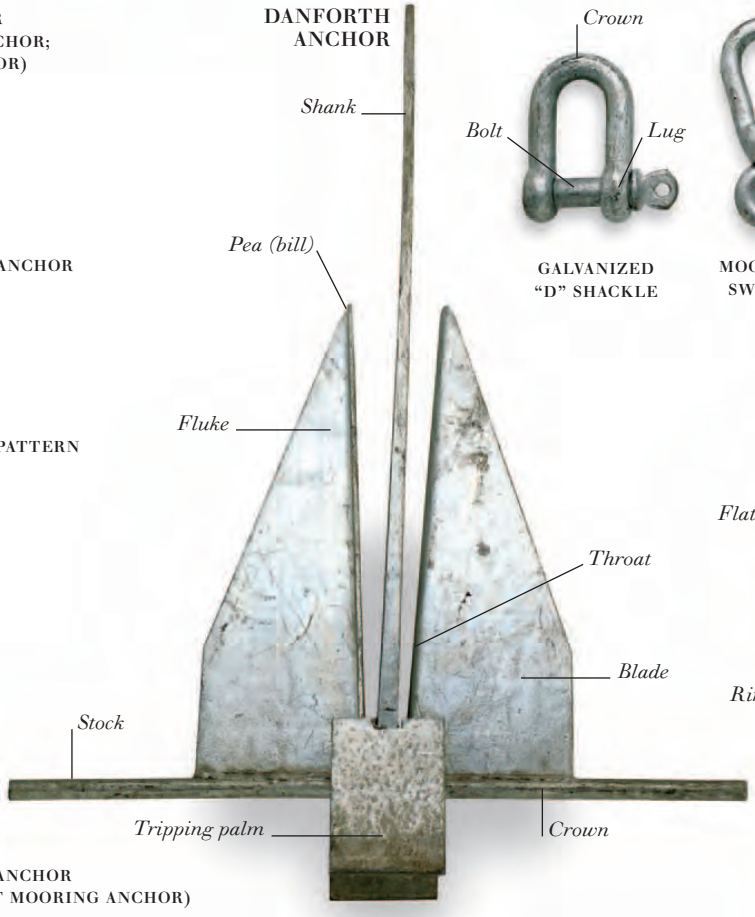
STOCKLESS ANCHOR

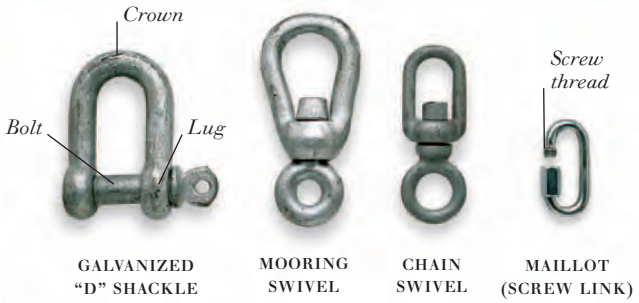
MUSHROOM ANCHOR (PERMANENT MOORING ANCHOR)

ANCHOR CHAIN

SHACKLE, SWIVELS, AND LINK

DANFORTH ANCHOR





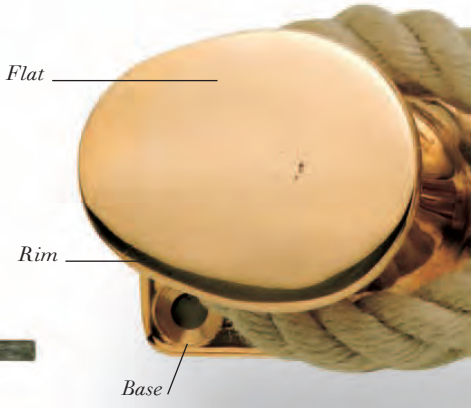
GALVANIZED "D" SHACKLE

MOORING SWIVEL

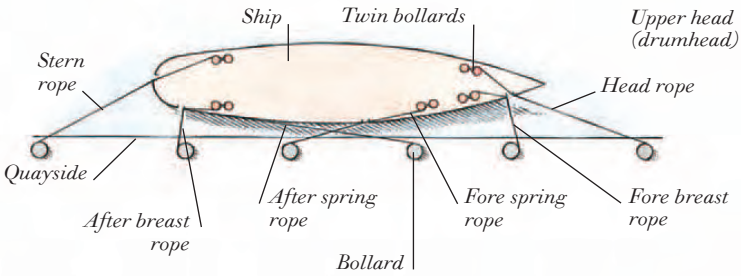
CHAIN SWIVEL

MAILLOT (SCREW LINK)

TWIN BOLLARDS WITH RAKED PILLARS AND A HAWSER (HEAVY ROPE)



BERTHING ROPES (HAWSERS)

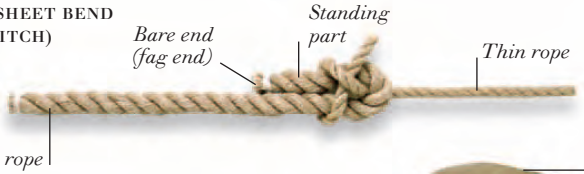


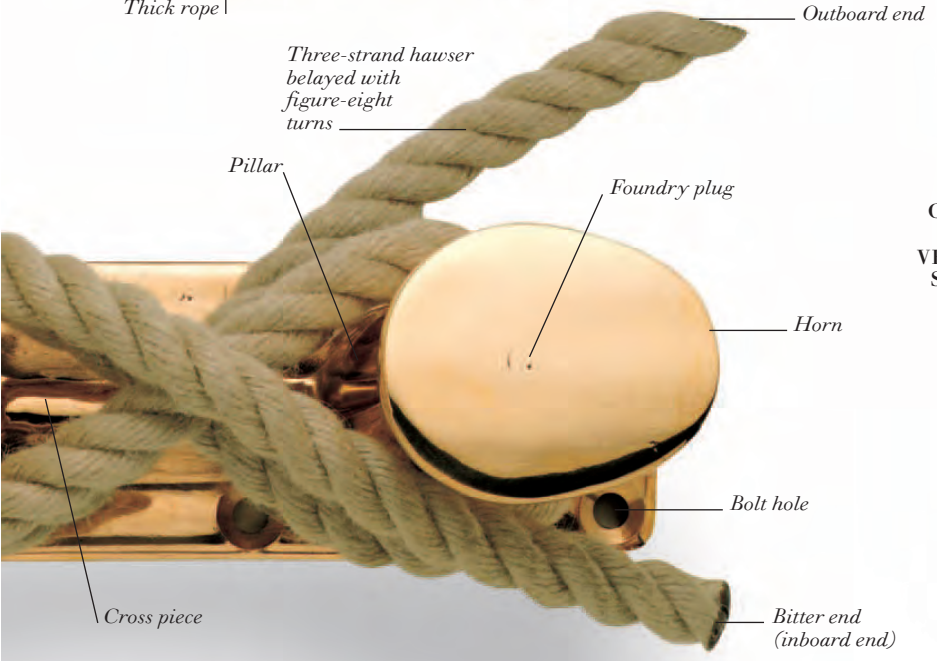
MOORING ROPE BENDS

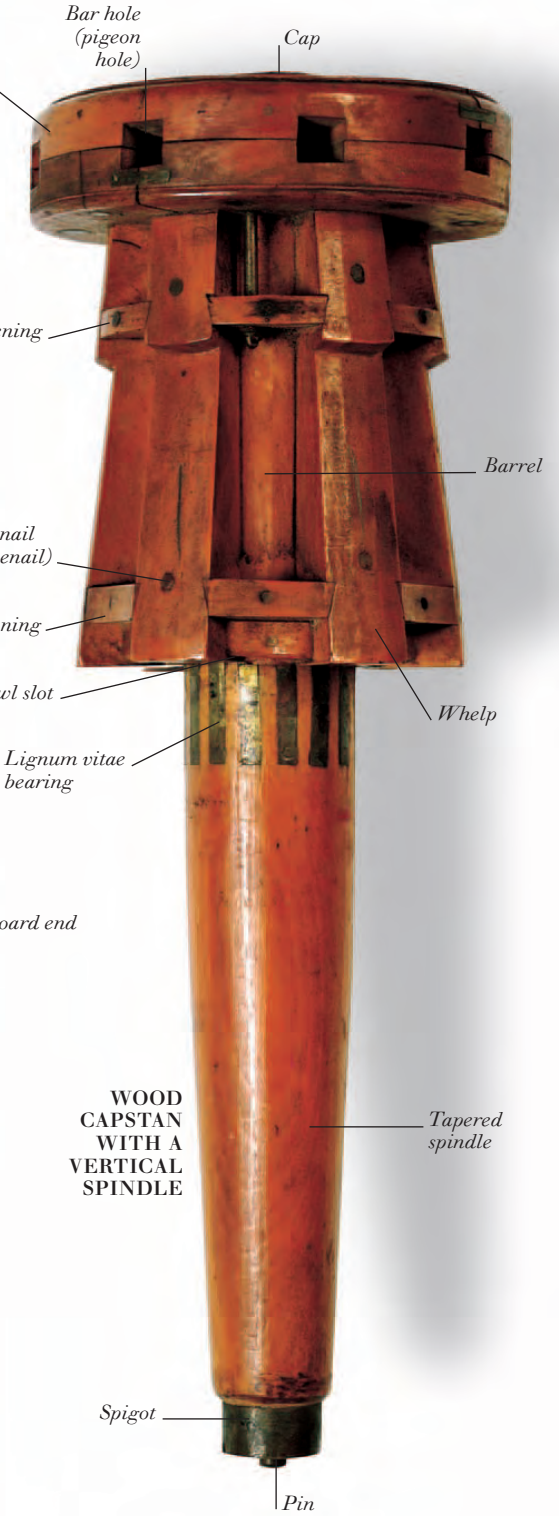
HAWSER BEND (TWO DOUBLE ROUND TURNS AND DOUBLE HALF HITCHES)

CARRICK BEND

SINGLE SHEET BEND (SWAB HITCH)



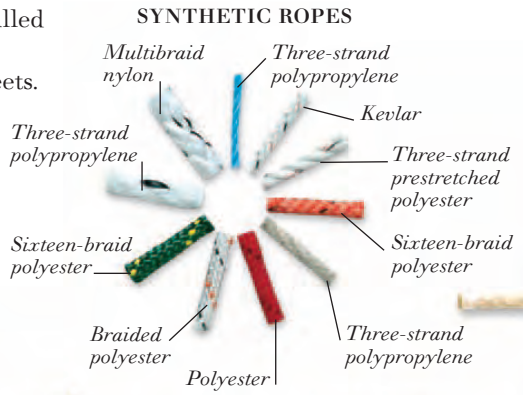


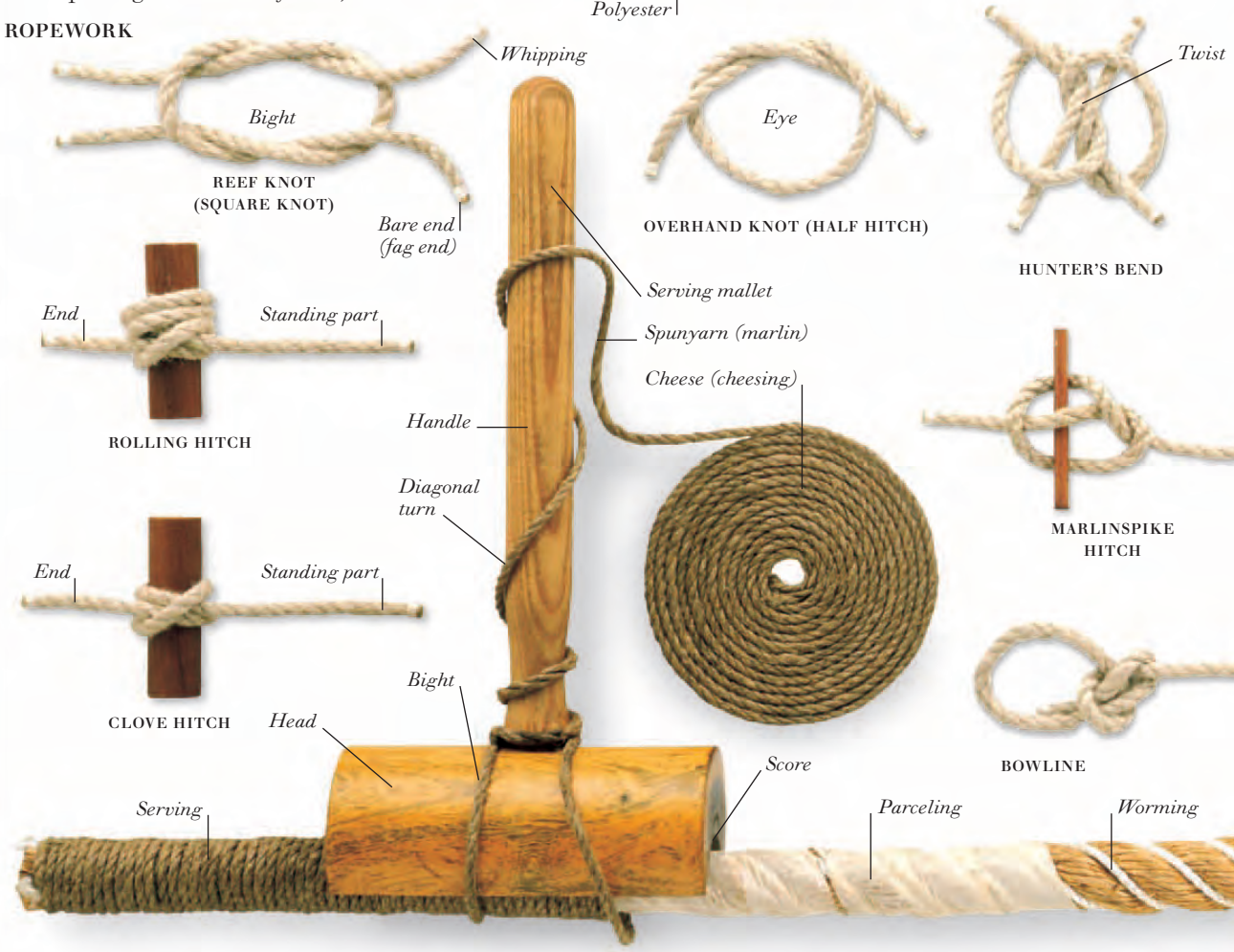


WOOD CAPSTAN WITH A VERTICAL SPINDLE

Ropes and knots

ALL KINDS OF ROPES ARE USED AT SEA, from thin twines and yarns to thick hawsers. Synthetic fibers have been developed specifically for use at sea. Nylon ropes stretch, and so are ideal for anchoring; polyester (frequently called by the trade name Dacron) has little stretch, so is ideal for halyards and sheets. Different knots have different uses. Knots that join two ropes are called bends; hitches join a rope to another object; and bowlines produce an eye (loop) in the end of a rope. Ropes can be joined by splicing (unraveling the ends and weaving them together) or seizing (lashing the ropes together side by side).





WORMING, PARCELING, AND SERVING

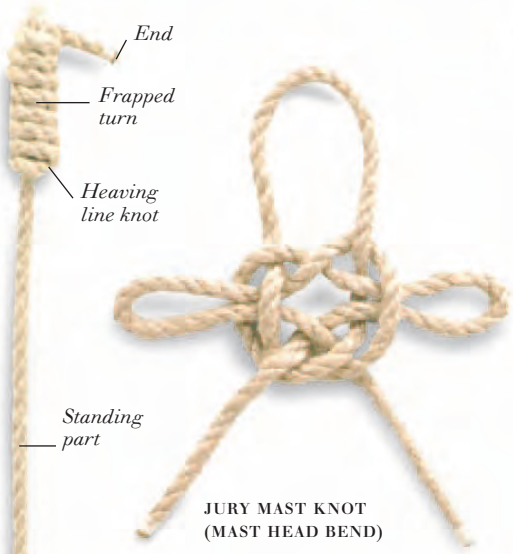
THUMB KNOT

SPANISH BOWLINE

FLAT SEIZING
(ROUND SEIZING)

DOUBLE CARRICK BEND

LIGHTERMAN'S HITCH

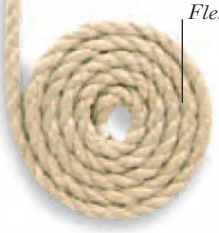


JURY MAST KNOT
(MAST HEAD BEND)

SHEET BEND (SWAB HITCH)

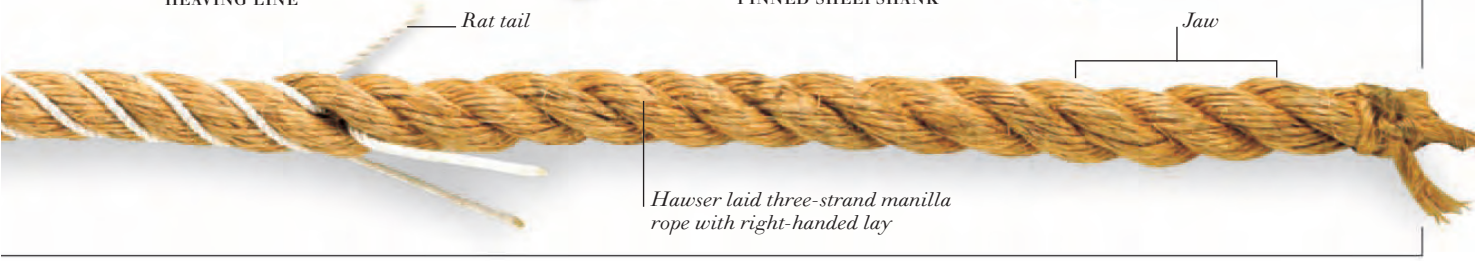
HEAVING LINE BEND

MANHARNESS KNOT
(BUTTERFLY KNOT;
ARTILLERY LOOP)



HEAVING LINE

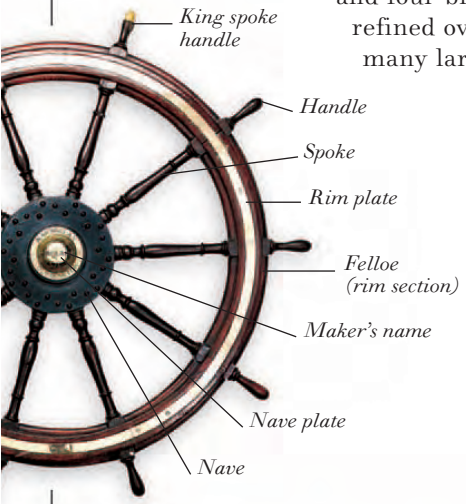
PINNED SHEEPSHANK



Paddle wheels and propellers

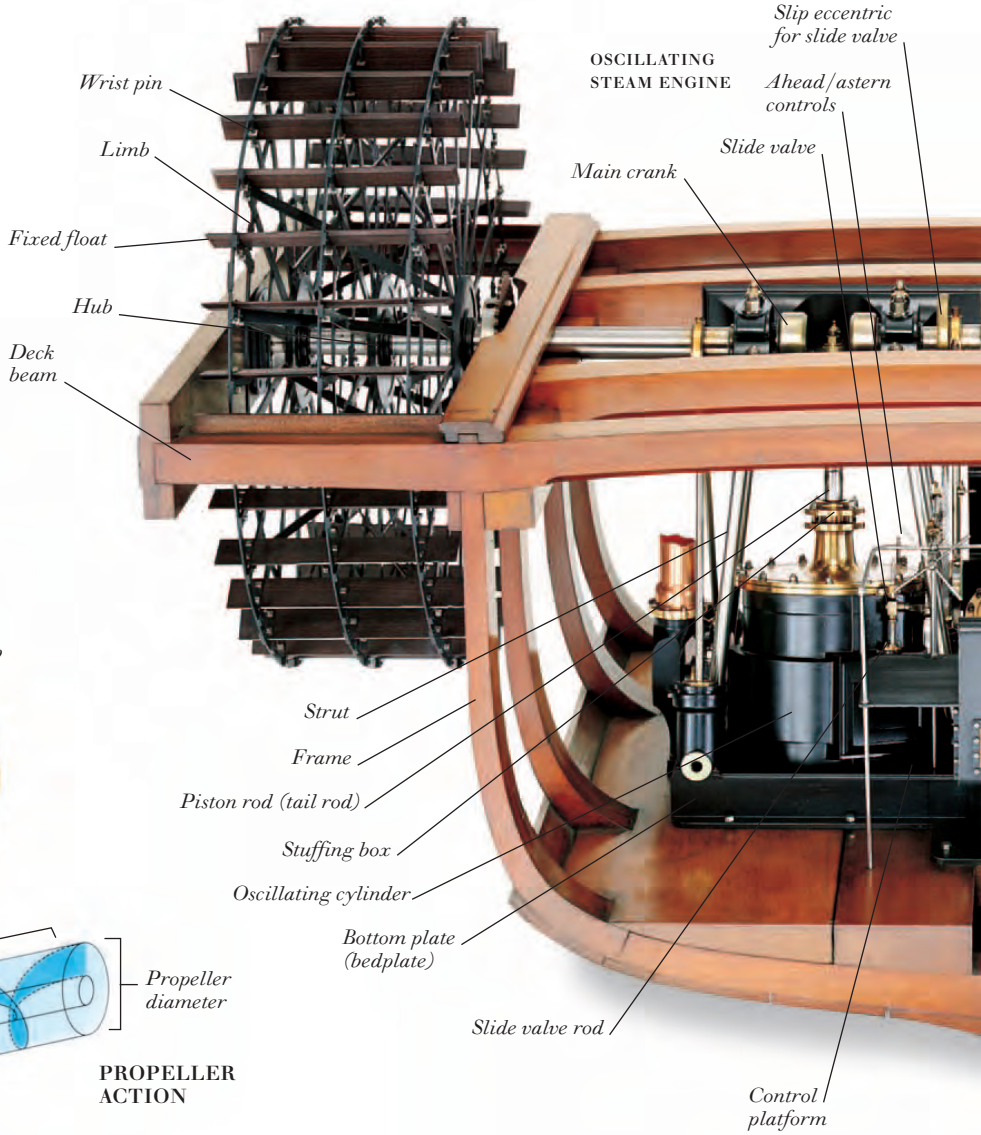
THE INVENTION OF THE STEAM ENGINE IN THE 18TH CENTURY made mechanically driven ships fitted with paddle wheels or propellers a viable alternative to sails. Paddle wheels have fixed or feathered floats, and the model shown below features both types. Feathered floats give more propulsive power than fixed floats because they are almost upright at all times in the water. Paddle wheels were superseded by the propeller on oceangoing vessels in the mid-19th century. Propellers are more efficient, work better in rough water, and are less vulnerable in collisions. The first propellers were two-bladed but later three- and four-bladed versions are more powerful; the shape and pitch of blades have also been refined over the years. At the beginning of the 18th century, tillers were superseded on many larger ships by the ship's wheel as a means of steering.

SHIP'S WHEEL

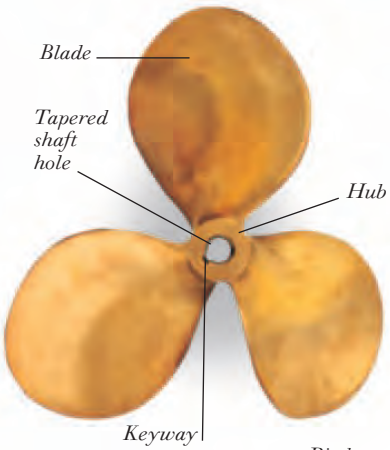


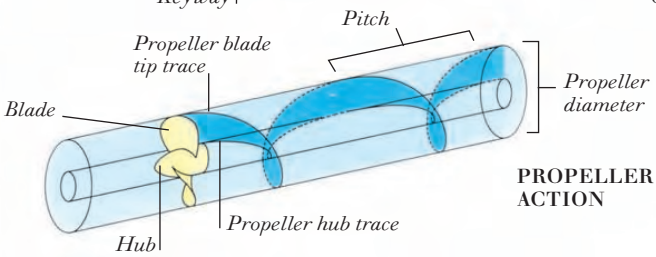
PADDLE WHEEL WITH FIXED FLOATS

OSCILLATING STEAM ENGINE



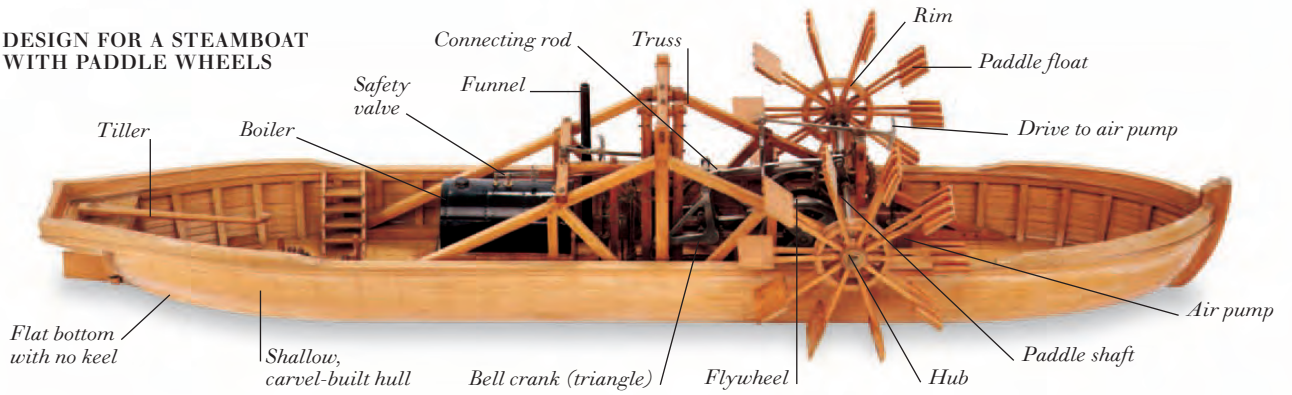
THREE-BLADED PROPELLER



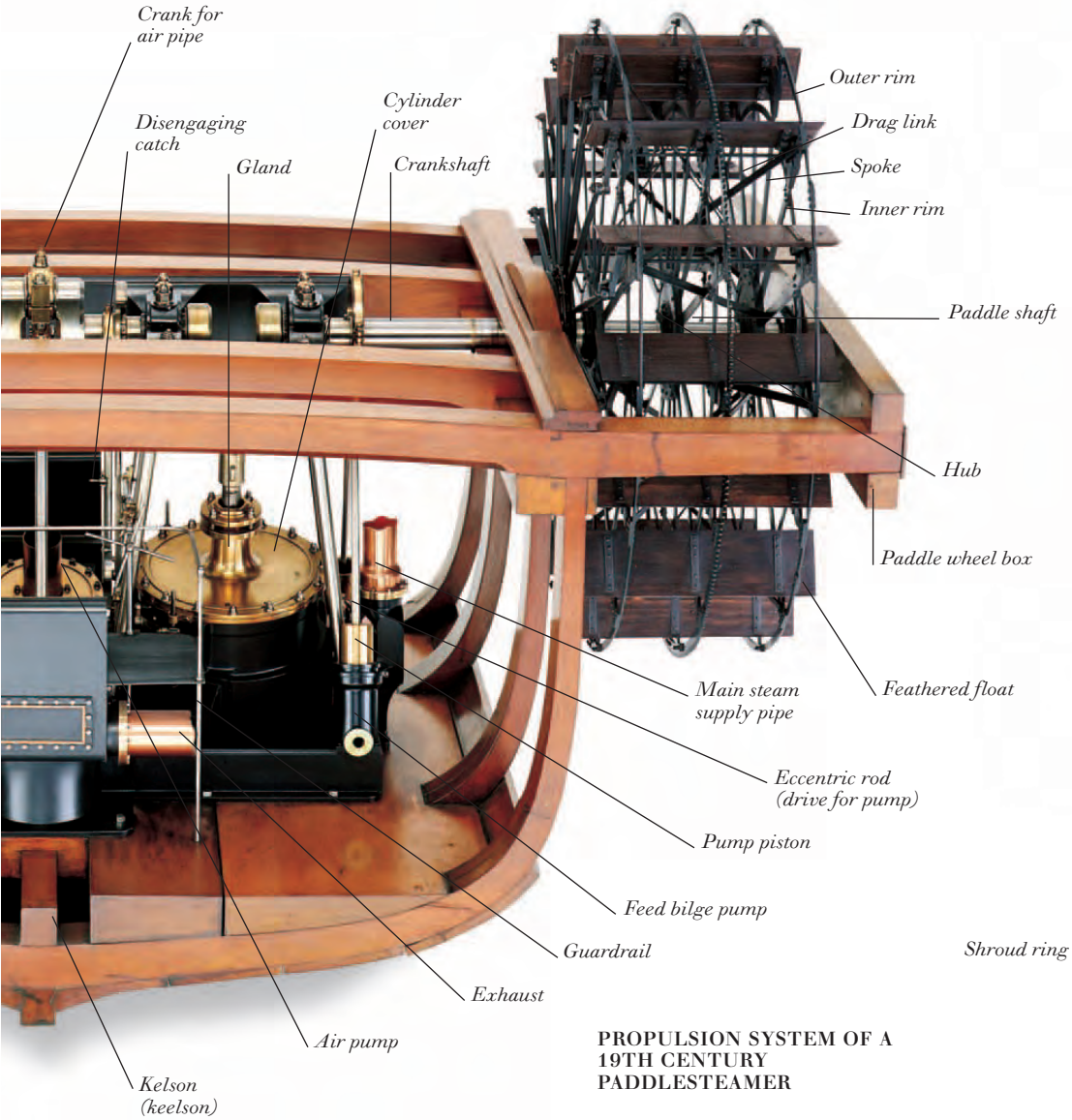


PROPELLER ACTION

DESIGN FOR A STEAMBOAT WITH PADDLE WHEELS



PADDLE WHEEL WITH FEATHERED FLOATS



TYPES OF PROPELLER

FROUDE'S EARLY TEST PROPELLER

TUG PROPELLER

THREE-BLADED PROPELLER

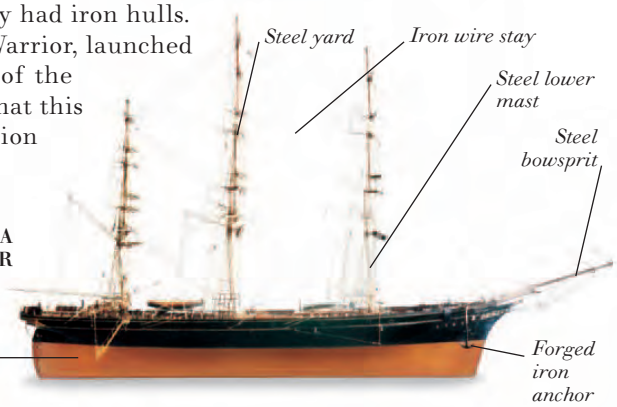
SHROUD RING PROPELLER

PROPULSION SYSTEM OF A 19TH CENTURY PADDLESTEAMER

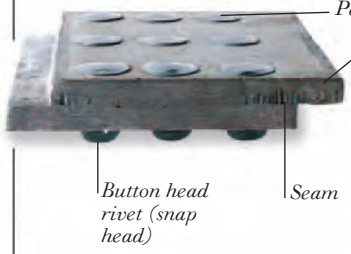
Anatomy of an iron ship

IRON PARTS WERE USED IN THE HULLS OF WOODEN SHIPS AS EARLY AS 1675, often in the same form as the wooden parts that they replaced. Eventually, as on the tea clipper Cutty Sark (below), iron rigging was found to be stronger than the traditional rope. The first "ironclads" were warships whose wooden hulls were protected by iron armor plates. Later ironclads actually had iron hulls. The model opposite is based on the British warship HMS Warrior, launched in 1860, the first battleship built entirely of iron. The plan of the iron paddlesteamer (bottom), built somewhat later, shows that this vessel was a sailing ship; but it also boasted a steam propulsion plant amidships that turned two side paddlewheels. Early iron hulls were made from plates that were painstakingly riveted together (as below), but by the 20th century vessels began to be welded together, whole sections at a time. The Second World War "liberty ship" was one of the first of these "production-line vessels."

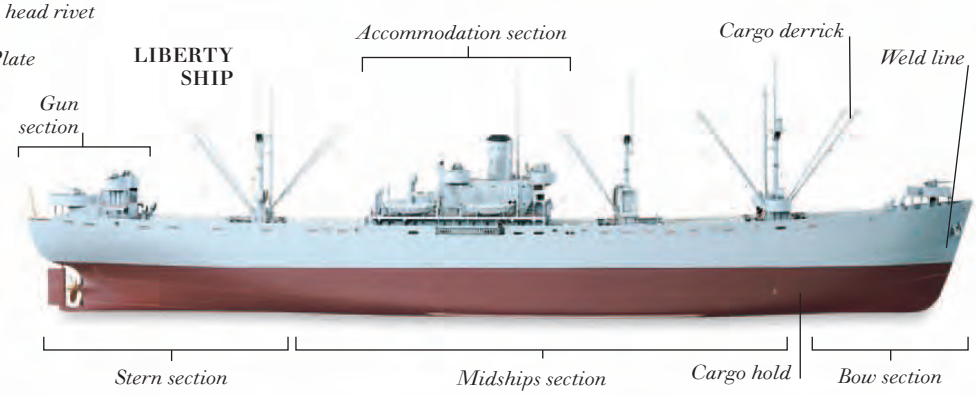
TEA CLIPPER



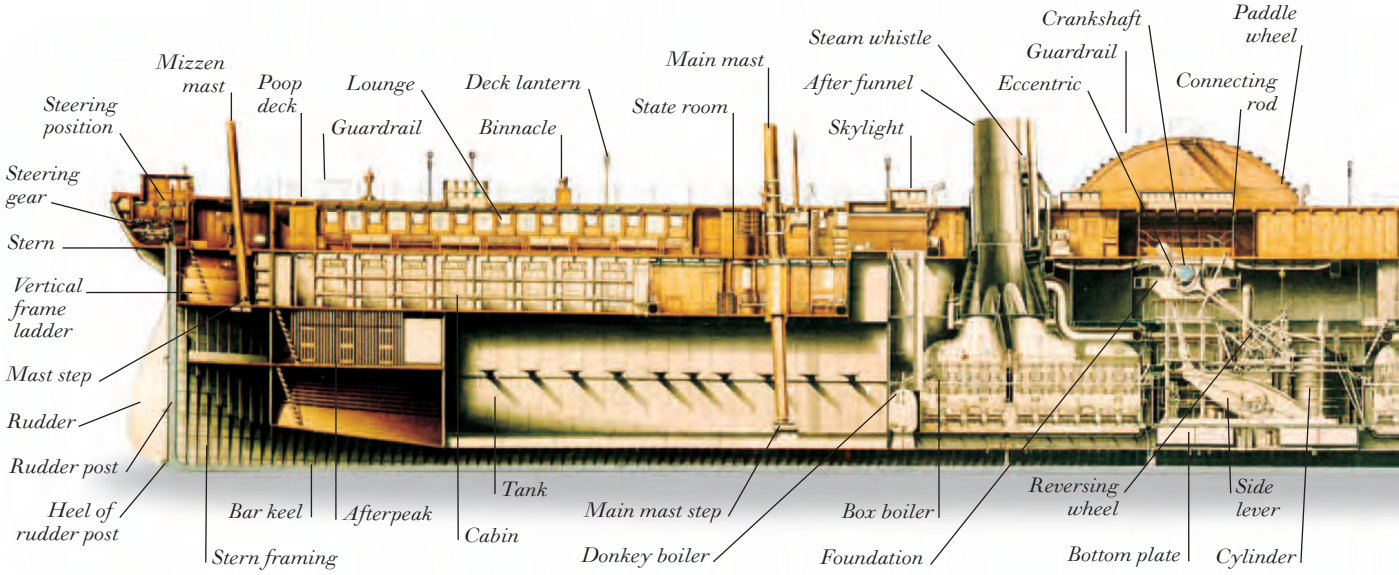
RIVETTED PLATES



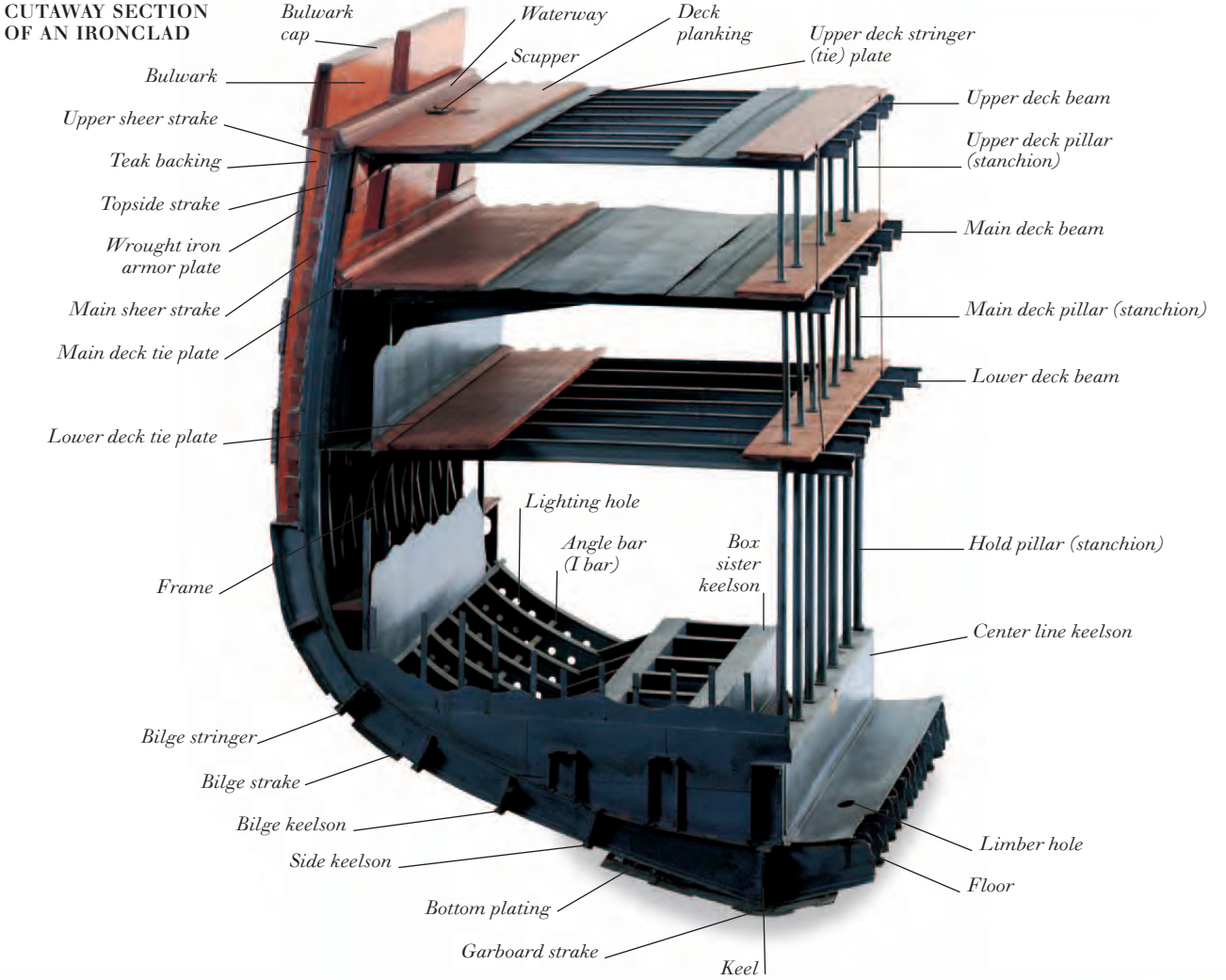
LIBERTY SHIP

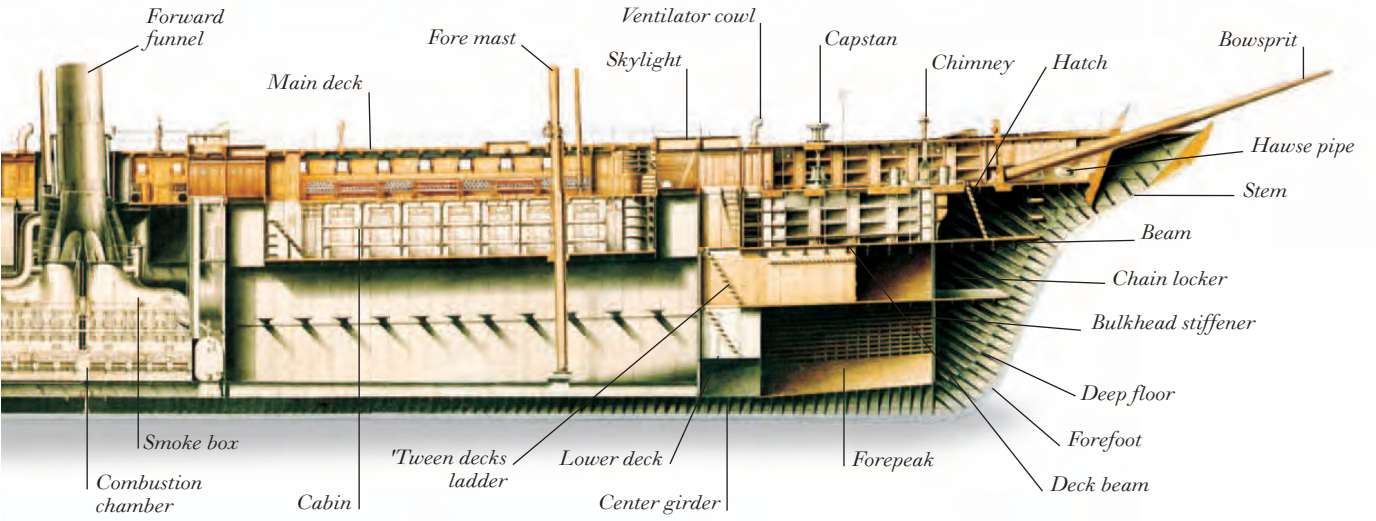


PLAN OF AN IRON PADDLESTEAMER



CUTAWAY SECTION OF AN IRONCLAD

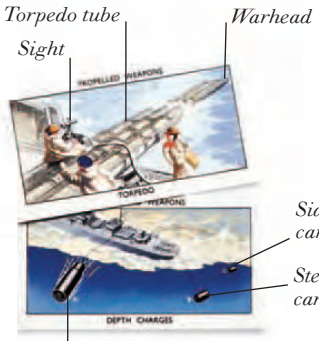




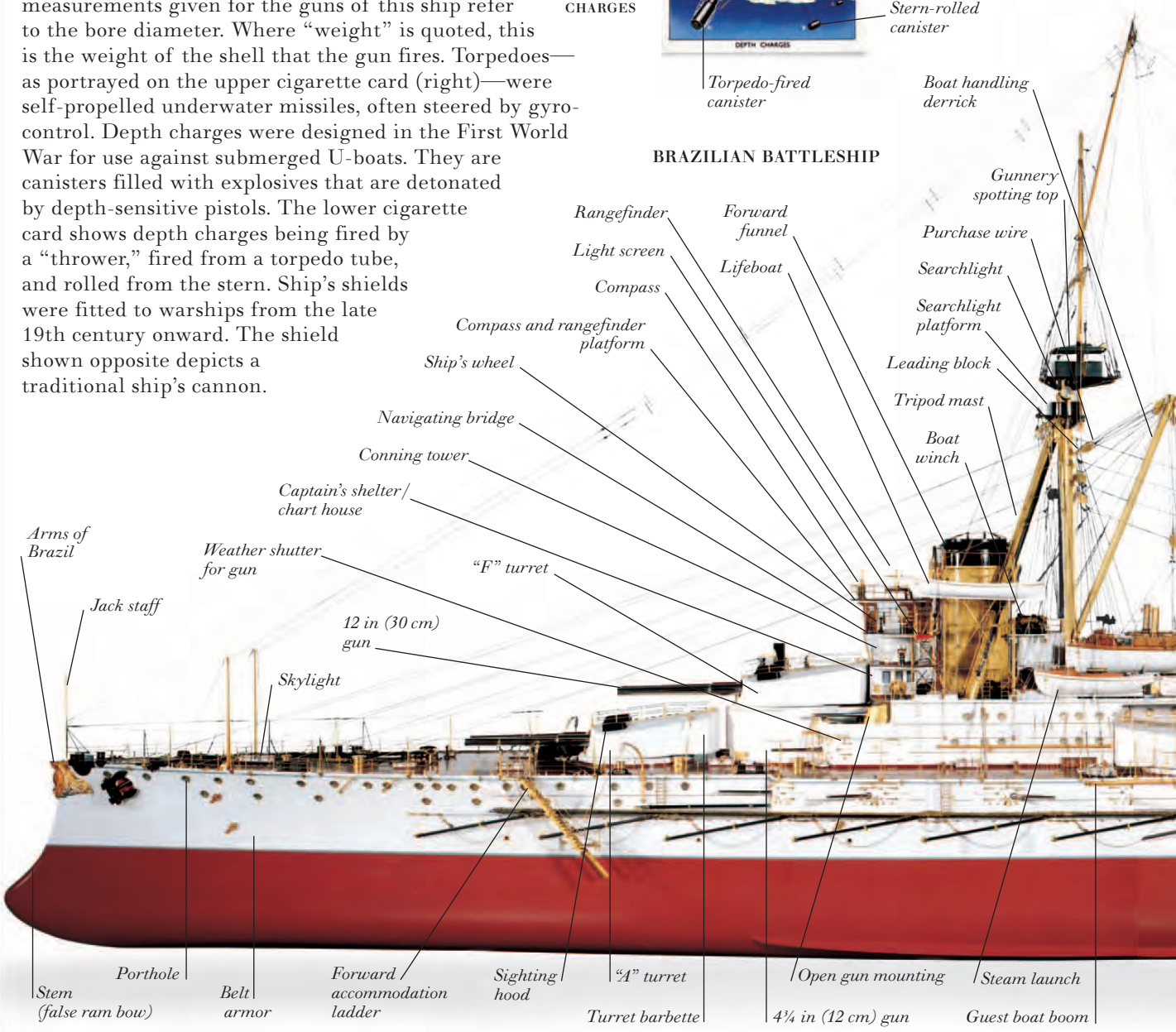
The battleship

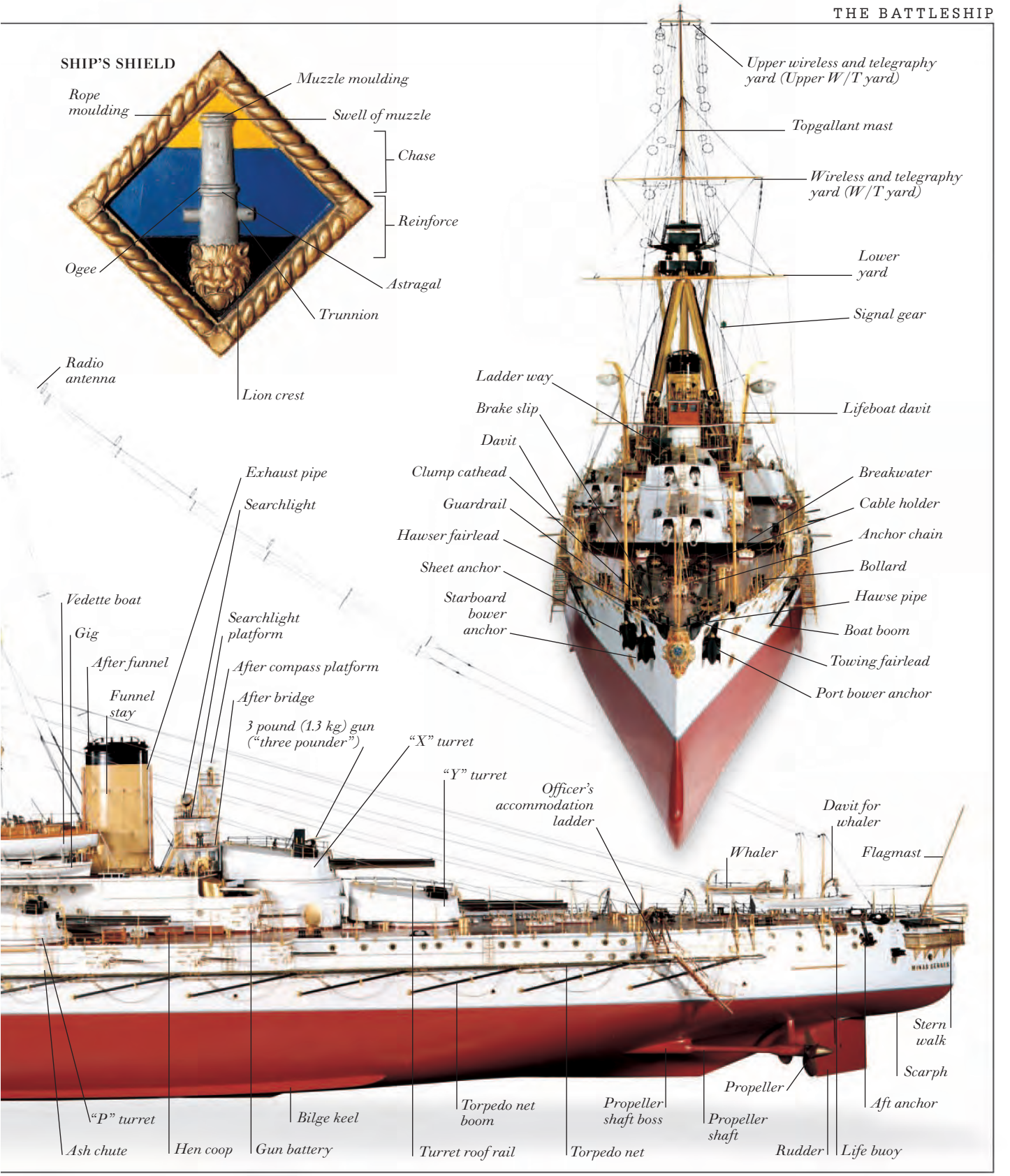
IN THE EARLY YEARS OF THE 20TH CENTURY, sea warfare—attacking enemy vessels or defending a ship—was revolutionized by the introduction of Dreadnought-type battleships like the Brazilian vessel below. These new ships combined the latest advances in steam propulsion, gunnery, and armor plating. The gun turret was designed to fire shells over huge distances. It was protected by armor 12 in (30 cm) thick. The measurements given for the guns of this ship refer to the bore diameter. Where "weight" is quoted, this is the weight of the shell that the gun fires. Torpedoes—as portrayed on the upper cigarette card (right)—were self-propelled underwater missiles, often steered by gyro-control. Depth charges were designed in the First World War for use against submerged U-boats. They are canisters filled with explosives that are detonated by depth-sensitive pistols. The lower cigarette card shows depth charges being fired by a "thrower," fired from a torpedo tube, and rolled from the stern. Ship's shields were fitted to warships from the late 19th century onward. The shield shown opposite depicts a traditional ship's cannon.

20TH CENTURY WEAPONRY



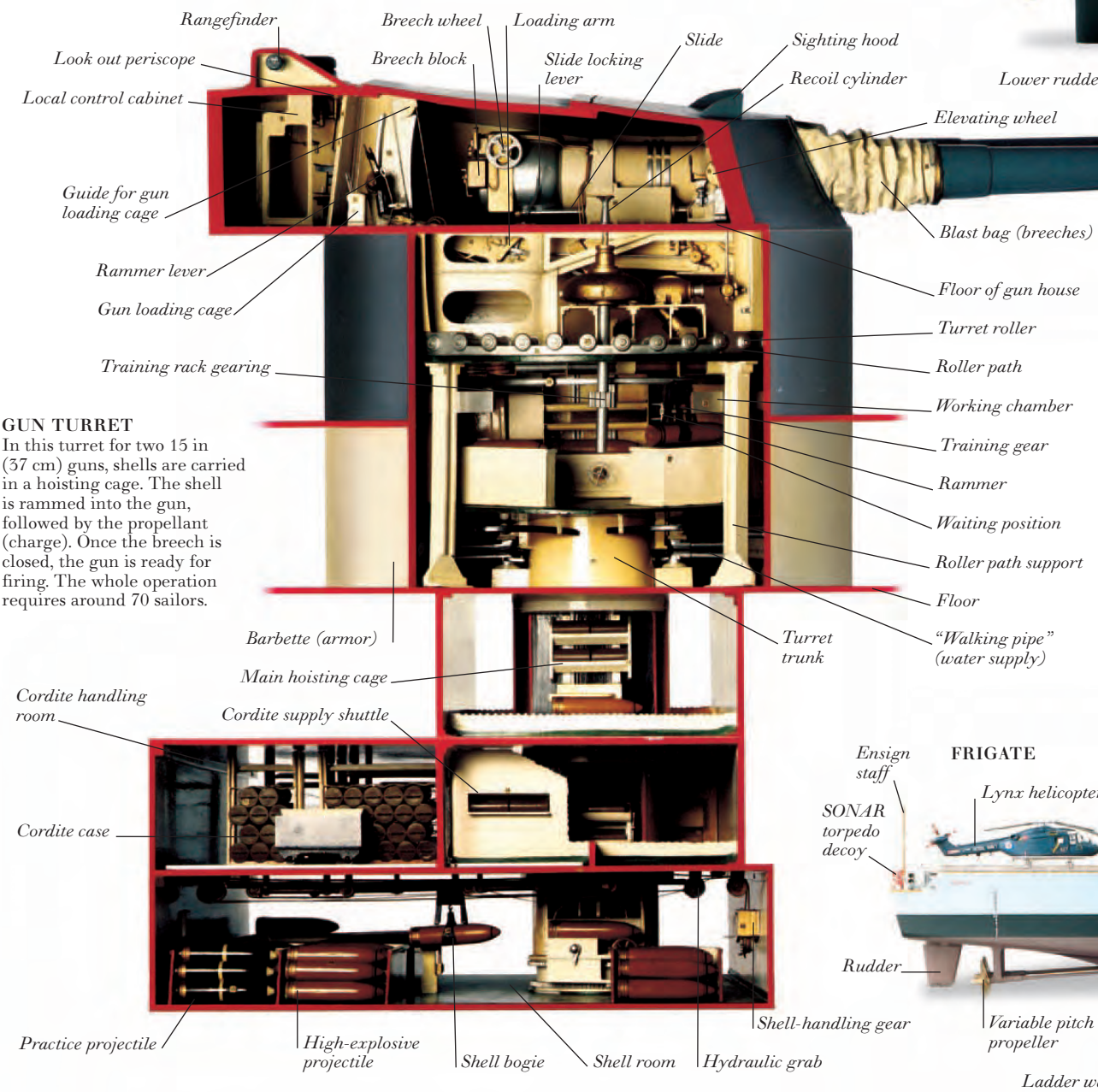
BRAZILIAN BATTLESHIP




SHIP'S SHIELD
Muzzle moulding
Rope moulding
Swell of muzzle
Chase
Reinforce
Ogee
Astragal
Trunnion
Radio antenna
Lion crest
Upper wireless and telegraphy yard (Upper W/T yard)
Topgallant mast
Wireless and telegraphy yard (W/T yard)
Lower yard
Signal gear
Ladder way
Brake slip
Davit
Clump cathead
Guardrail
Hawser fairlead
Sheet anchor
Starboard bower anchor
Lifeboat davit
Breakwater
Cable holder
Anchor chain
Bollard
Hawse pipe
Boat boom
Towing fairlead
Port bower anchor
Exhaust pipe
Searchlight
Vedette boat
Gig
Searchlight platform
After funnel
After compass platform
Funnel stay
After bridge
3 pound (1.3 kg) gun ("three pounder")
"X" turret
"Y" turret
Officer's accommodation ladder
Davit for whaler
Whaler
Flagmast
Stern walk
Scarph
Propeller
Aft anchor
"P" turret
Bilge keel
Torpedo net boom
Propeller shaft boss
Propeller shaft
Ash chute
Hen coop
Gun battery
Turret roof rail
Torpedo net
Rudder
Life buoy

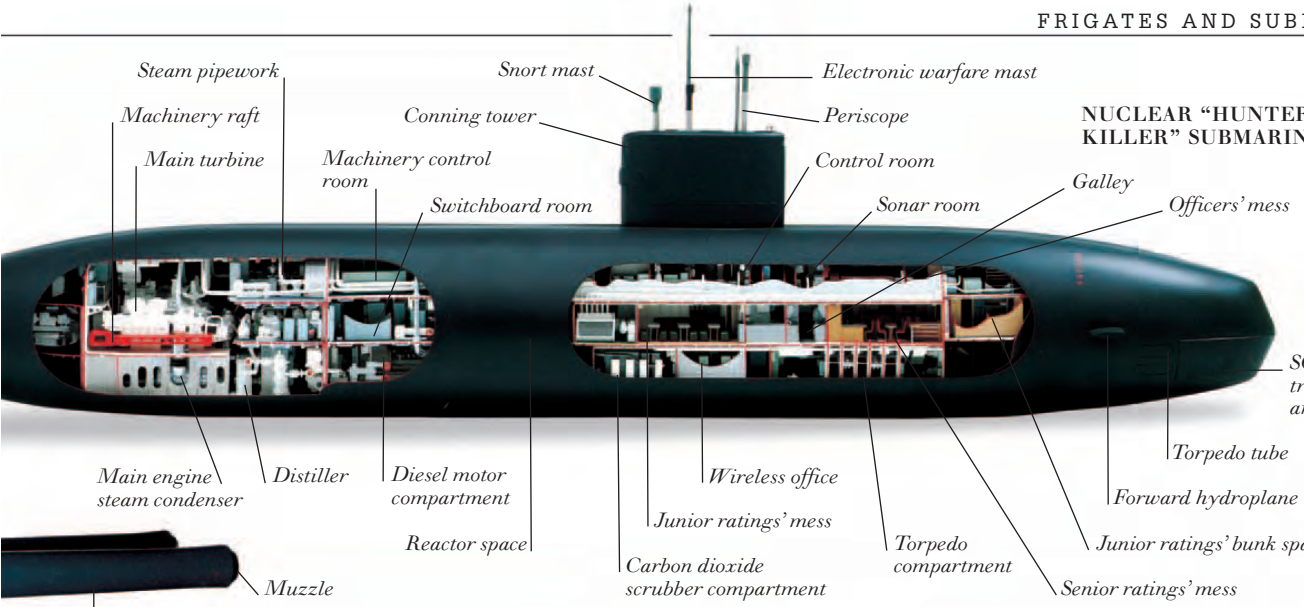
Frigates and submarines

FROM THE MID-19TH CENTURY, ARMORED SHIPS provided a new challenge to enemy craft. In response, huge revolving gun turrets were developed. These could fire in any direction, could be loaded from the breech very rapidly, and, instead of cannonballs, they discharged exploding shells. Modern fighting ships, like the frigate, combine heavy ship-borne armament with light helicopter weaponry. Submarines function below the surface of the sea. Their speed and ability to fire missiles from under water are their major assets. The nuclear submarine can stay under water for several years without refueling.



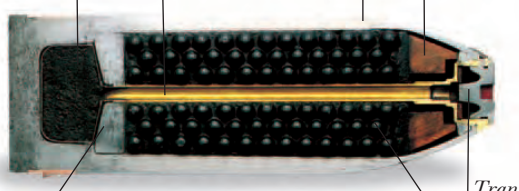
GUN TURRET
In this turret for two 15 in (37 cm) guns, shells are carried in a hoisting cage. The shell is rammed into the gun, followed by the propellant (charge). Once the breech is closed, the gun is ready for firing. The whole operation requires around 70 sailors.

NUCLEAR "HUNTER-KILLER" SUBMARINE

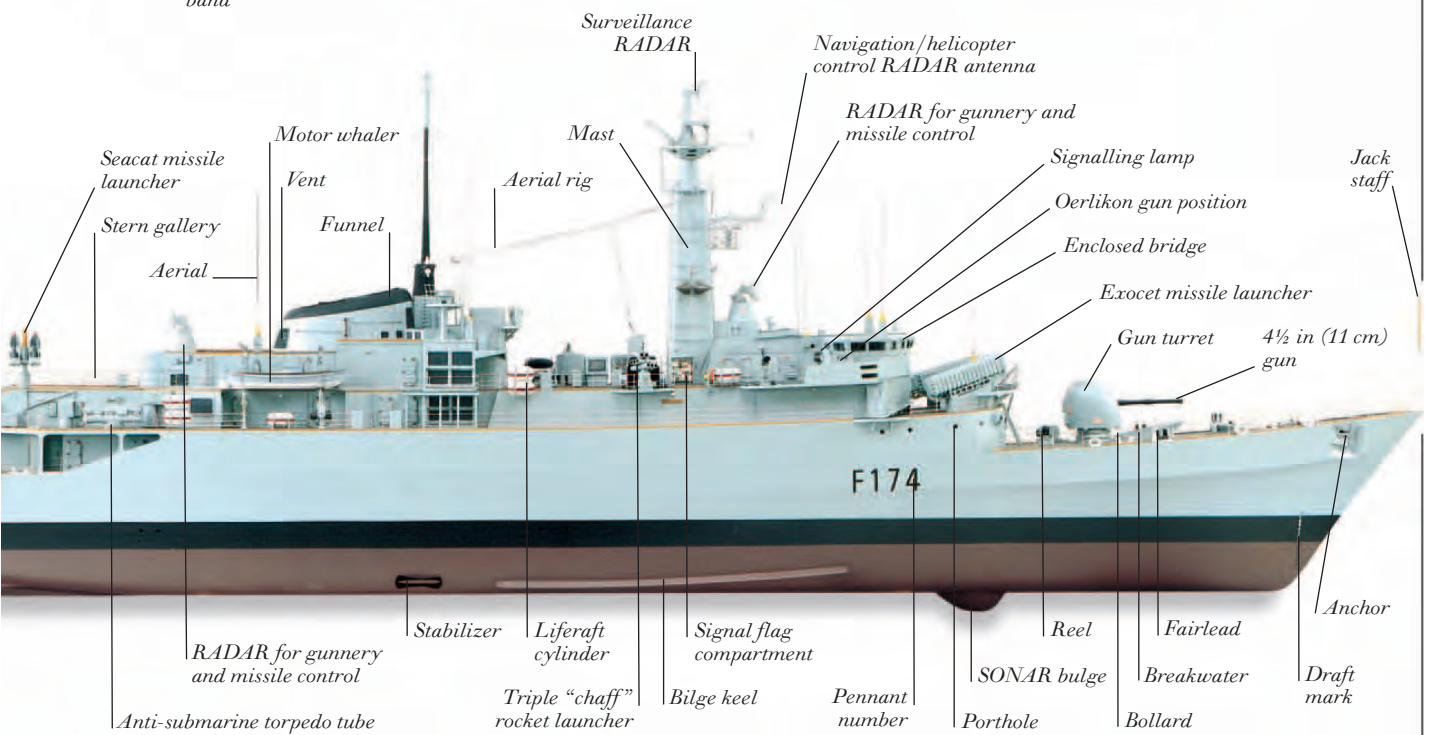


6 in (15 cm) SHELL
This shell is designed to burst in the air above its target.

SHELL CASE



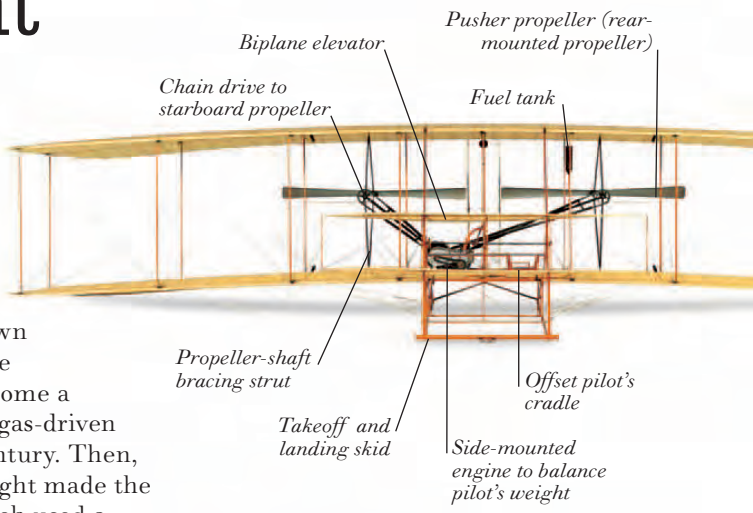
CROSS-SECTION OF THE SHELL



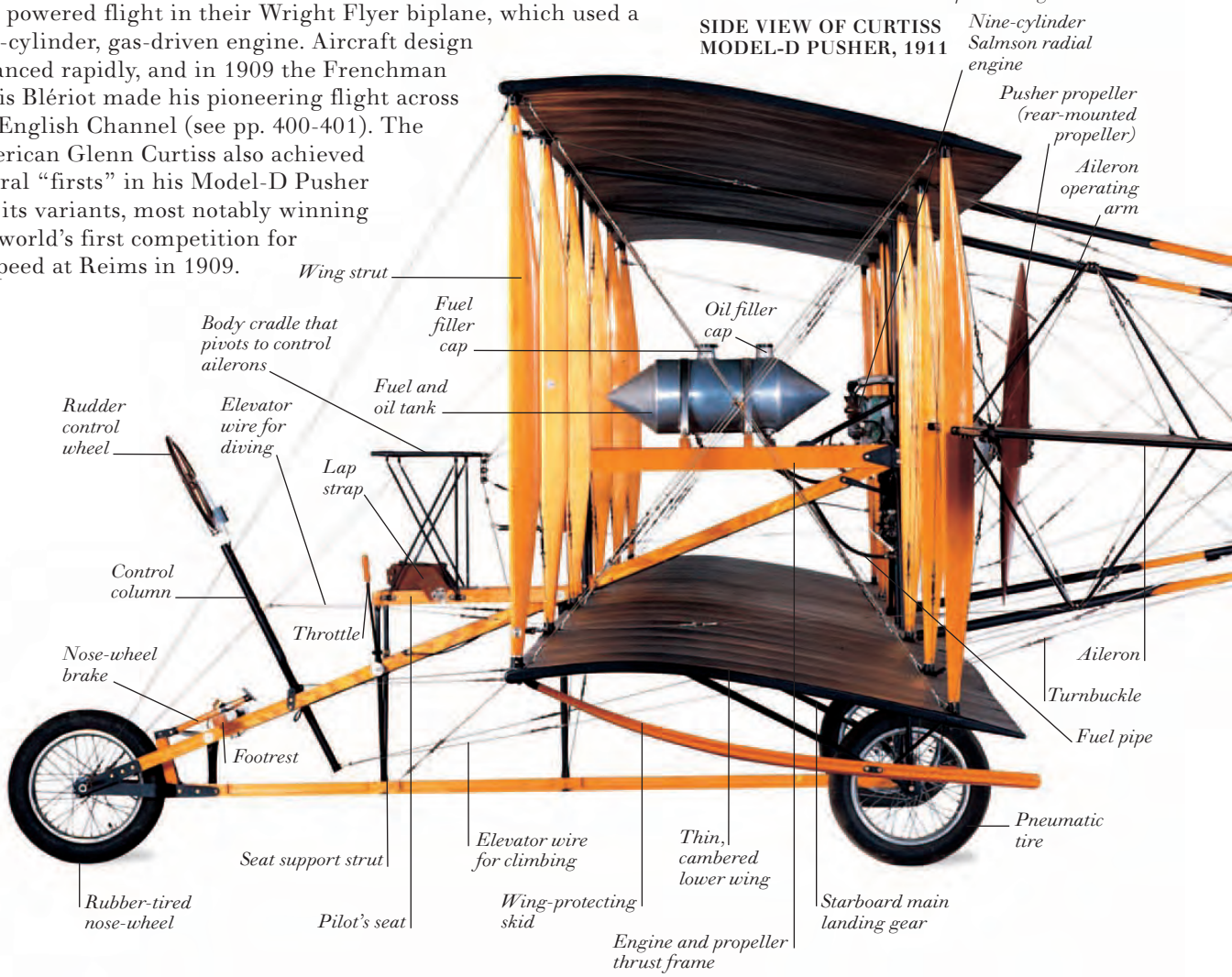
Pioneers of flight

FLIGHT HAS FASCINATED MANKIND for centuries, and countless unsuccessful flying machines have been designed. The first successful flight was made by the French Montgolfier brothers in 1783, when they flew a balloon over Paris. The next major advance was the development of gliders, notably by the Englishman Sir George Cayley, who in 1845 designed the first glider to make a sustained flight, and by the German Otto Lil ienthal, who became known as the world's first pilot because he managed to achieve controlled flights. However, powered flight did not become a practical possibility until the invention of lightweight, gas-driven internal combustion engines at the end of the 19th century. Then, in 1903, the American brothers Orville and Wilbur Wright made the first powered flight in their Wright Flyer biplane, which used a four-cylinder, gas-driven engine. Aircraft design advanced rapidly, and in 1909 the Frenchman Louis Blériot made his pioneering flight across the English Channel (see pp. 400-401). The American Glenn Curtiss also achieved several "firsts" in his Model-D Pusher and its variants, most notably winning the world's first competition for airspeed at Reims in 1909.

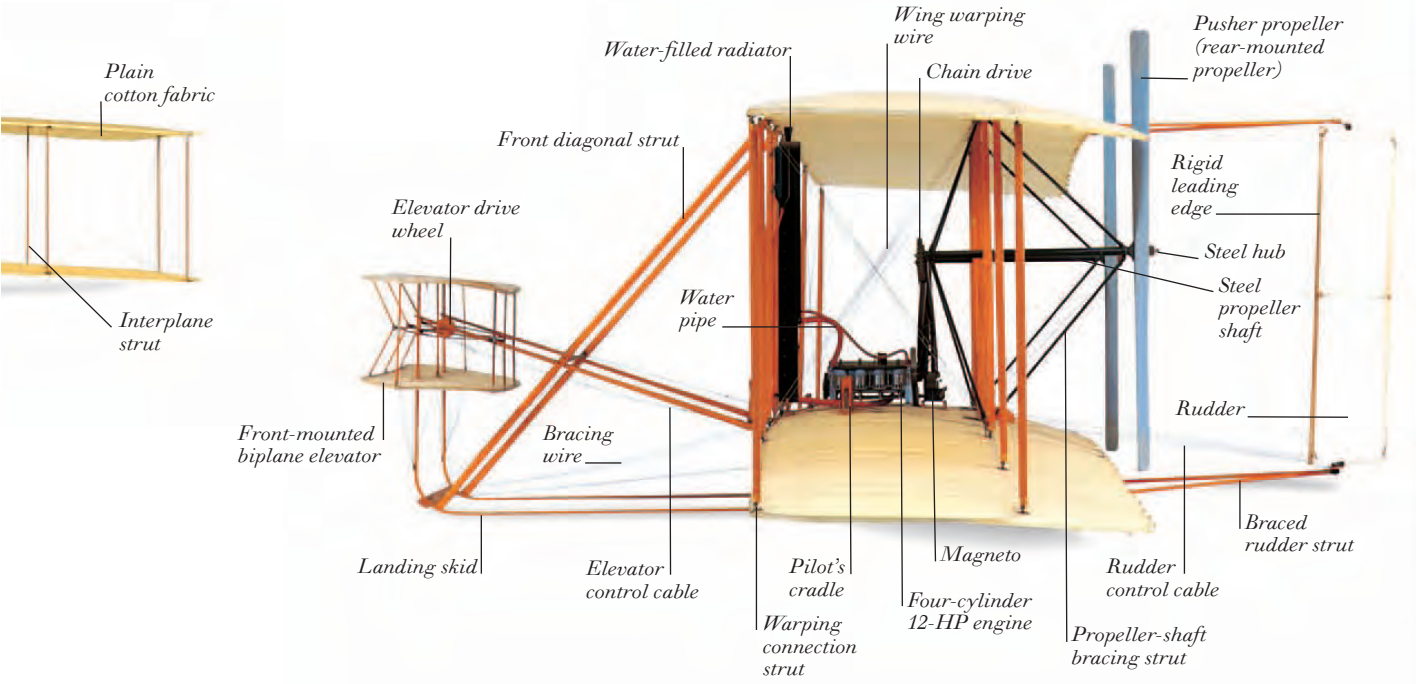
FRONT VIEW OF WRIGHT FLYER, 1903

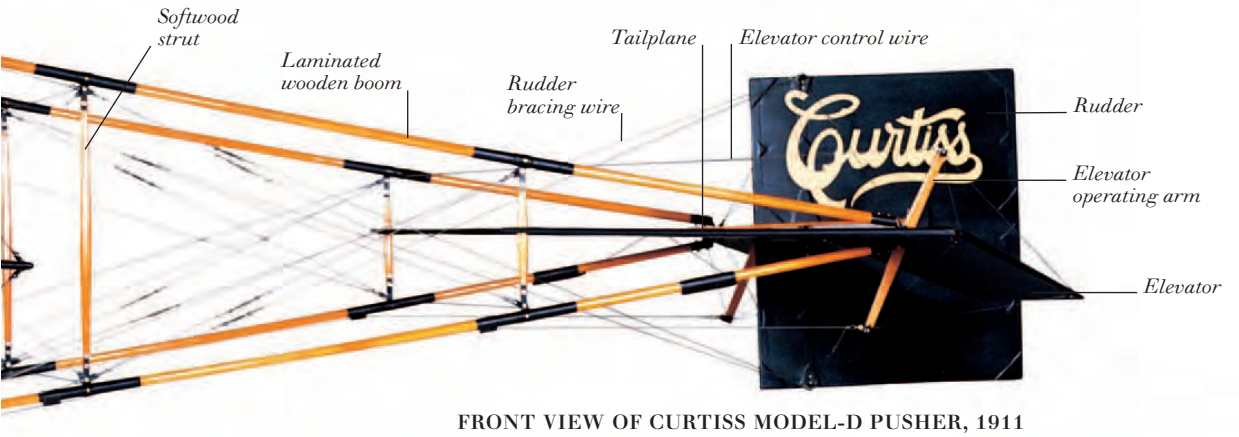


SIDE VIEW OF CURTISS MODEL-D PUSHER, 1911

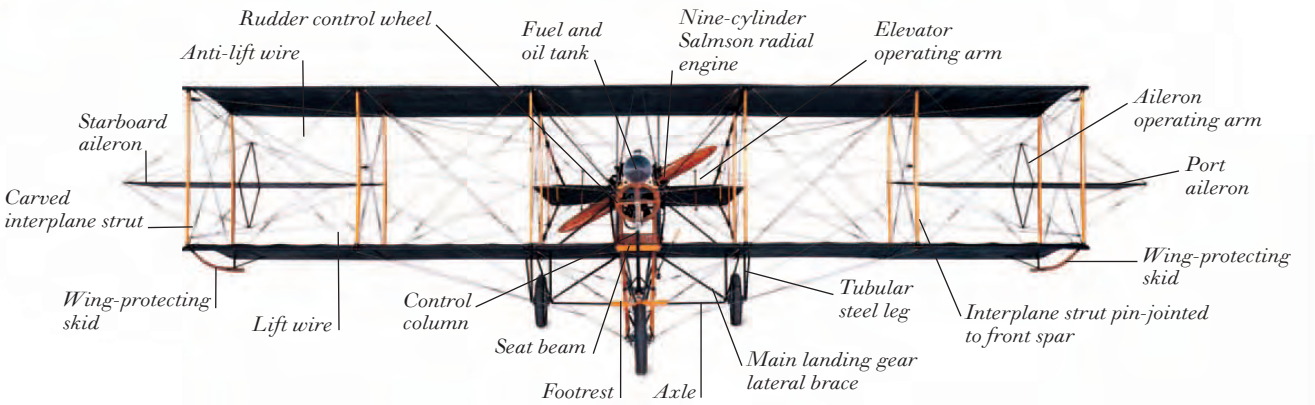


SIDE VIEW OF WRIGHT FLYER, 1903





FRONT VIEW OF CURTISS MODEL-D PUSHER, 1911

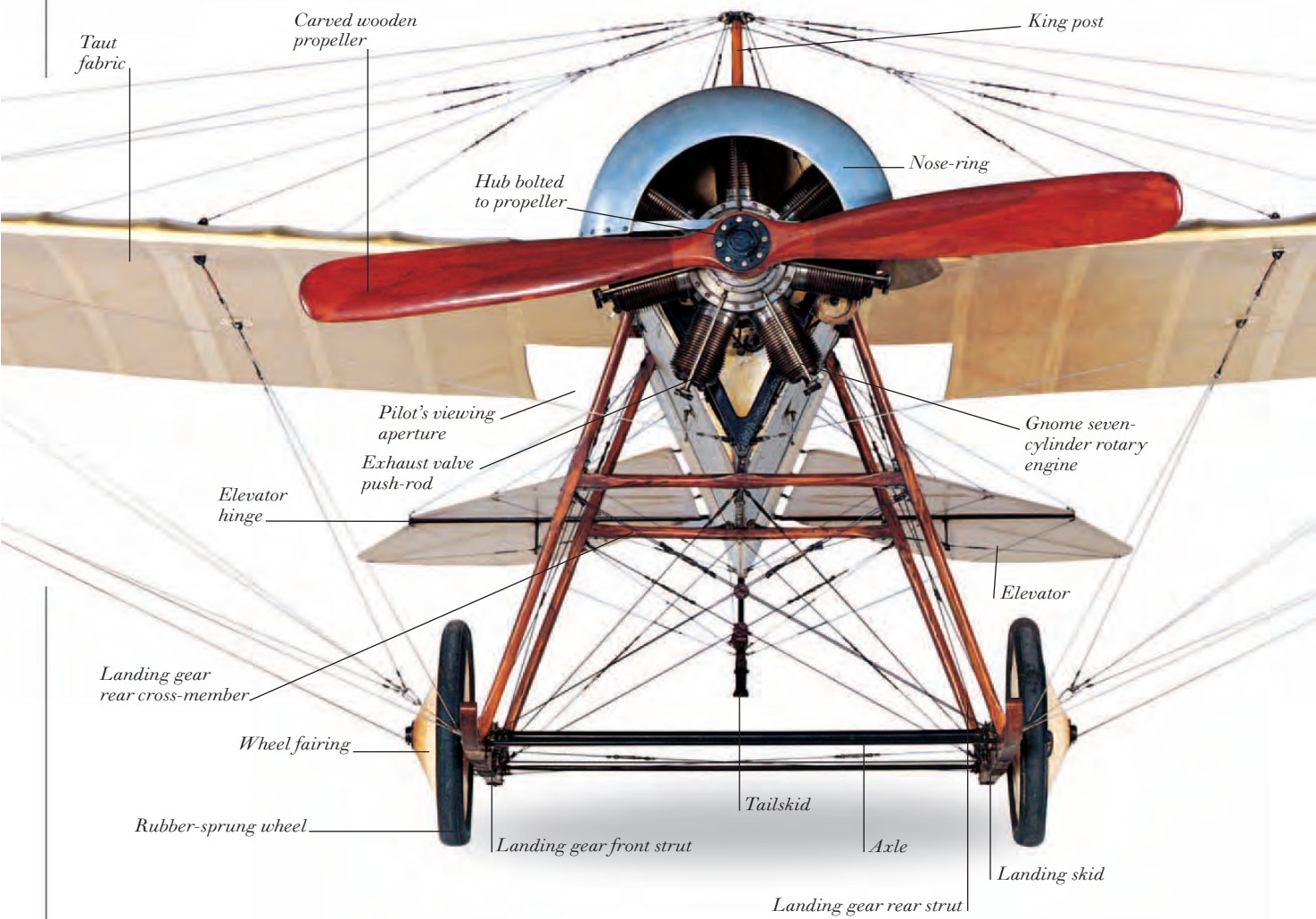


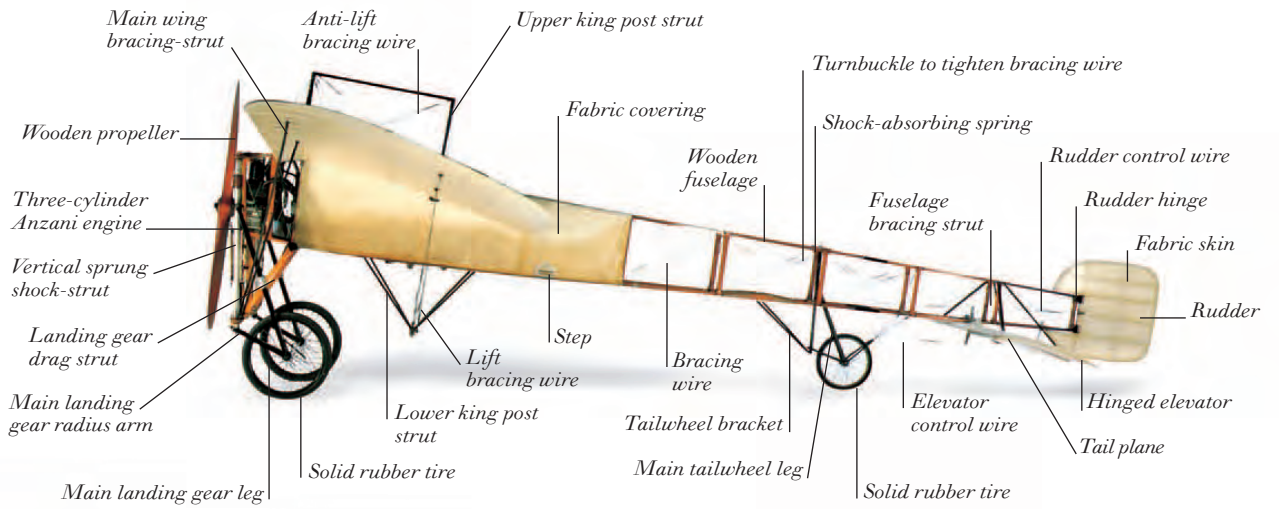
Early monoplanes

RUMPLER MONOPLANE, 1908

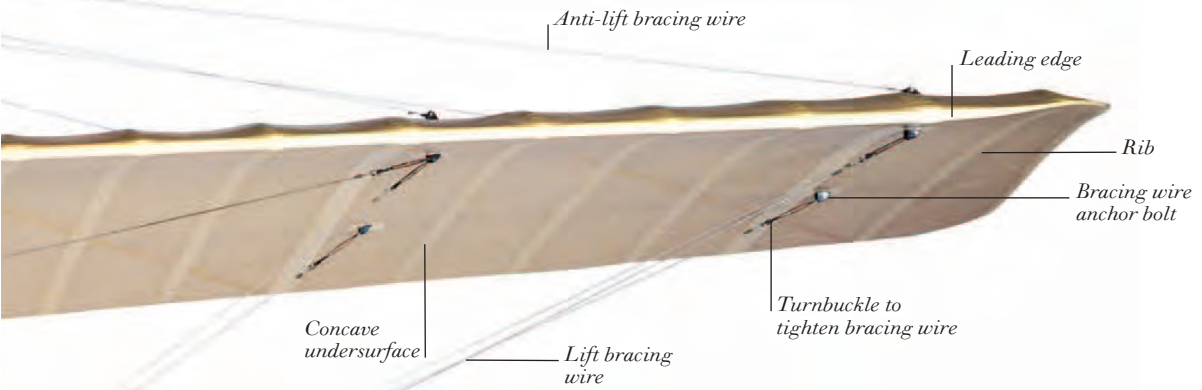
MONOPLANES HAVE ONE WING on each side of the fuselage. The principal disadvantage of this arrangement in early, wooden-framed aircraft was that single wings were weak and required strong wires to brace them to king posts above and below the fuselage. However, single wings also had advantages: they experienced less drag than multiple wings, allowing greater speed; they also made aircraft more manoeuvrable because single wings were easier to warp (twist) than double wings, and warping the wings was how pilots controlled the roll of early aircraft. By 1912, the French pilot Louis Blériot had used a monoplane to make the first flight across the English Channel, and the Briton Robert Blackburn and the Frenchman Armand Deperdussin had proved the greater speed of monoplanes. However, a spate of crashes caused by broken wings discouraged monoplane production, except in Germany, where all-metal monoplanes were developed in 1917. The wings of all-metal monoplanes did not need strengthening by struts or bracing wires, but despite this, such planes were not widely adopted until the 1930s.

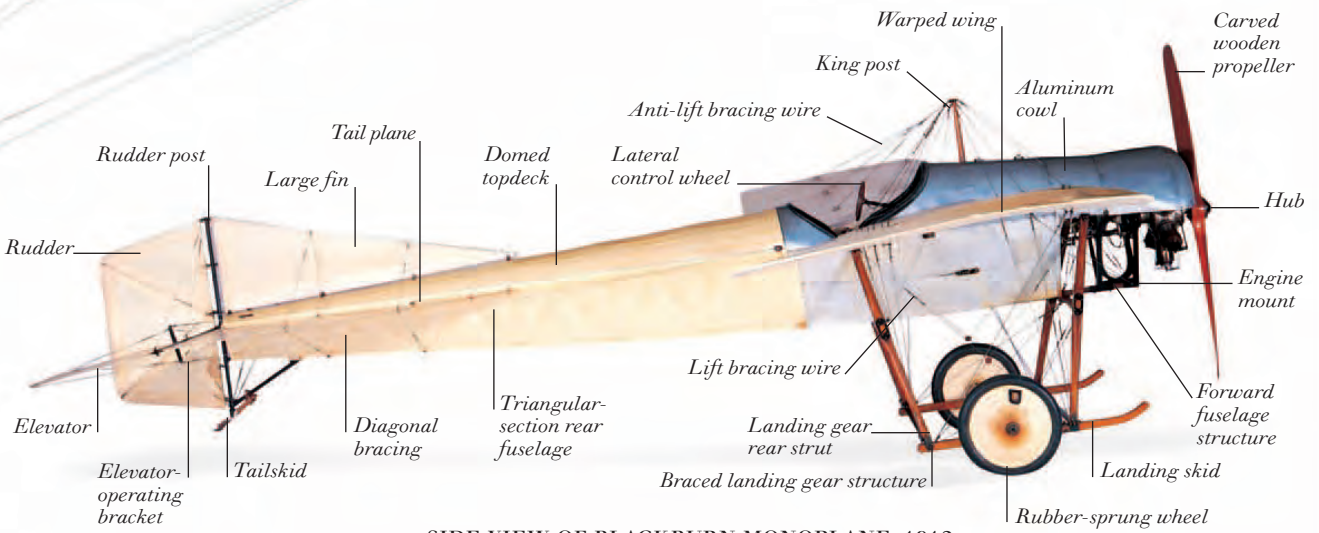
FRONT VIEW OF BLACKBURN MONOPLANE, 1912





SIDE VIEW OF BLÉRIOT XI, 1909



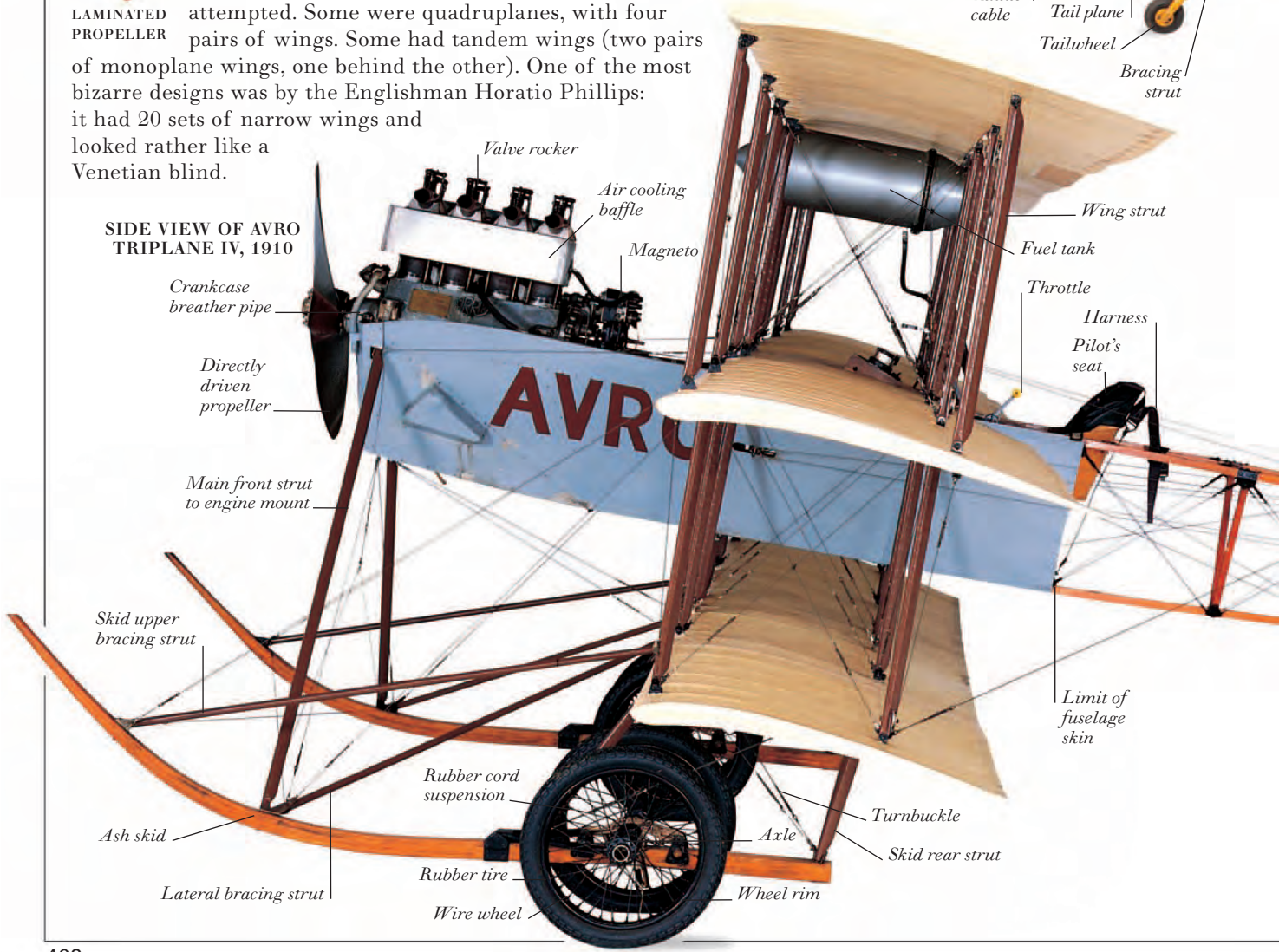


SIDE VIEW OF BLACKBURN MONOPLANE, 1912

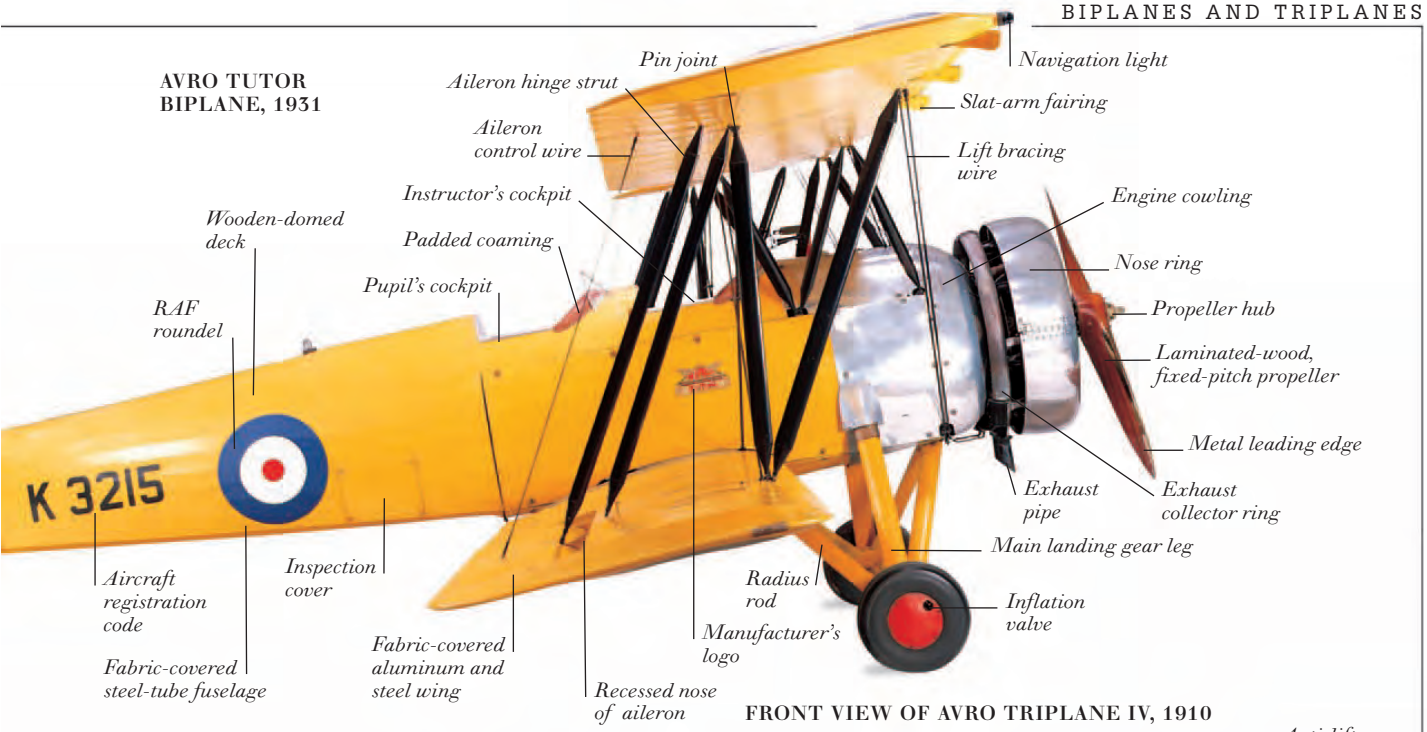
Biplanes and triplanes

LAMINATED PROPELLER

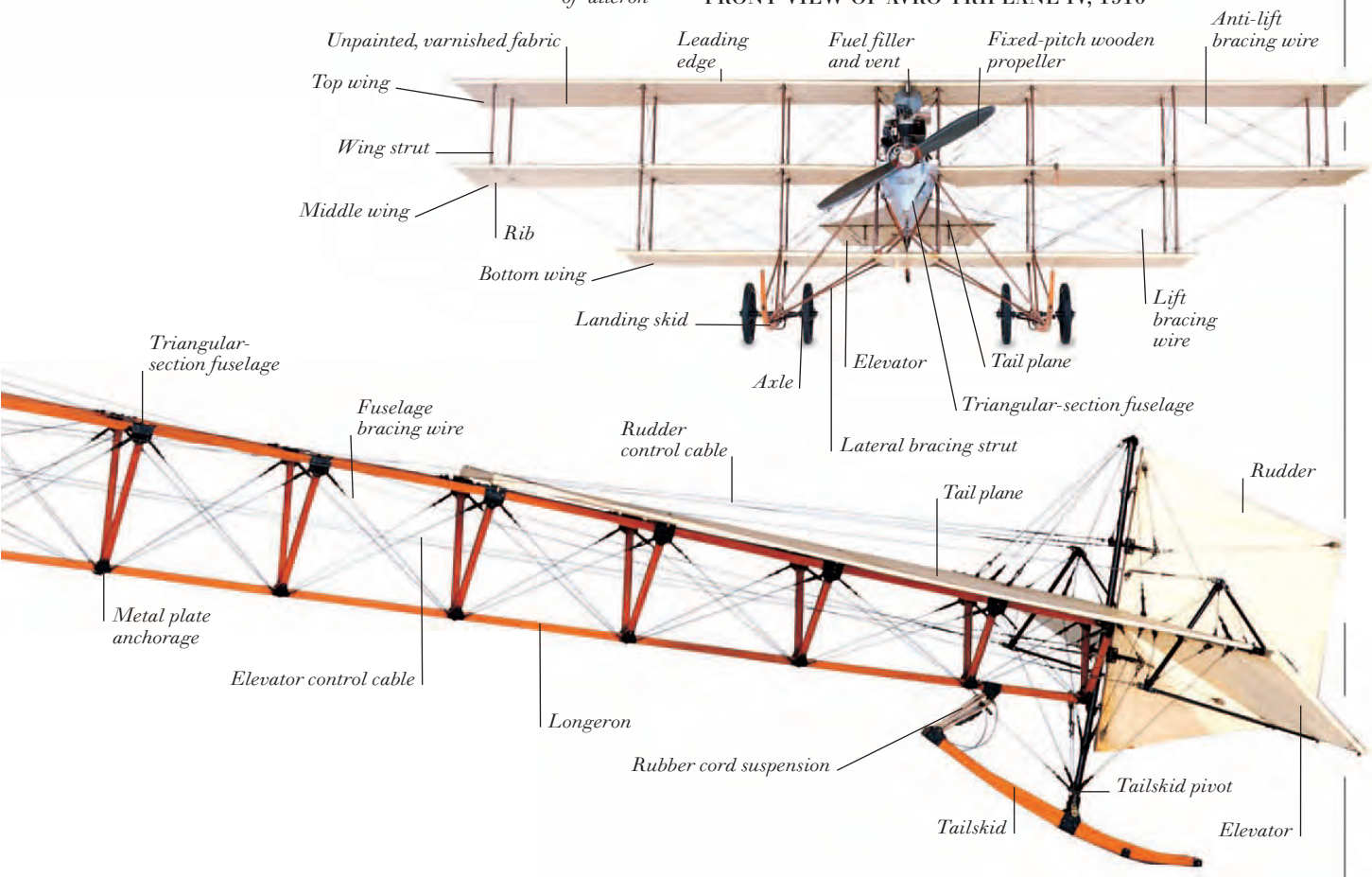
BIPLANES DOMINATED AIRCRAFT DESIGN until the 1930s, largely because some early monoplanes (see pp. 400-401) were too fragile to withstand the stresses of flight. The struts between biplanes' wings made the wings strong compared with those of early monoplanes, although the greater surface area of biplanes' wings increased drag and reduced speed. Many aircraft designers also developed triplanes, which had a particular advantage over biplanes: more wings meant a shorter wingspan to achieve the same lifting power, and a shorter wingspan gave greater manoeuvrability. Triplanes were most successful as fighters during World War I, the German Fokker triplane being a notable example. However, the greater maneuverability of triplanes was no advantage for normal flying and so most manufacturers continued to make biplanes. Many other aircraft designs were attempted. Some were quadruplanes, with four pairs of wings. Some had tandem wings (two pairs of monoplane wings, one behind the other). One of the most bizarre designs was by the Englishman Horatio Phillips: it had 20 sets of narrow wings and looked rather like a Venetian blind.



SIDE VIEW OF AVRO TRIPLANE IV, 1910



FRONT VIEW OF AVRO TRIPLANE IV, 1910

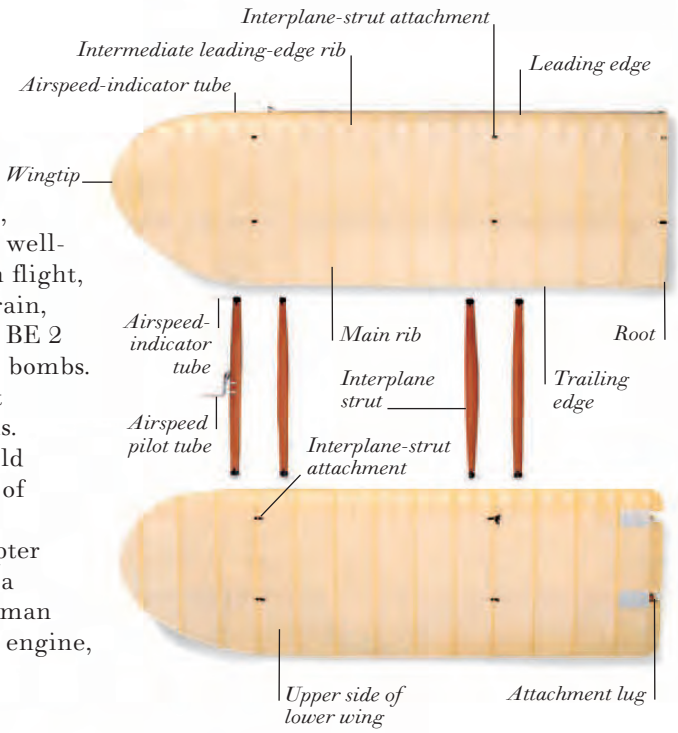


World War I aircraft

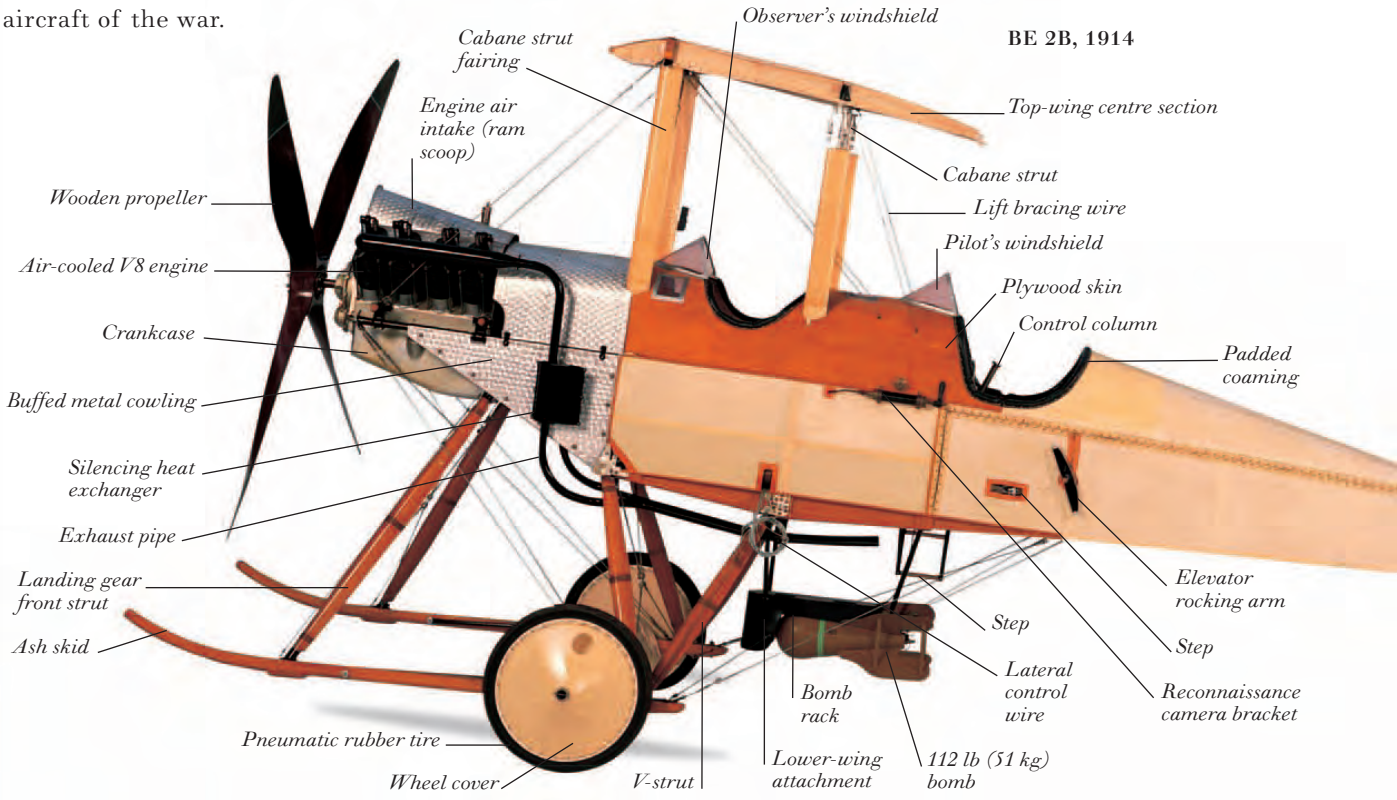
FLYING HELMET

WHEN WORLD WAR I STARTED in 1914, the main purpose of military aircraft was reconnaissance. The British-built BE 2, of which the BE 2B was a variant, was well-suited to this duty; it was very stable in flight, allowing the occupants to study the terrain, take photographs, and make notes. The BE 2 was also one of the first aircraft to drop bombs. One of the biggest problems for aircraft designers during the war was mounting machine-guns. On aircraft that had front-mounted propellers, the field of fire was restricted by the propeller and other parts of the aircraft. The problem was solved in 1915 by the Dutchman Anthony Fokker, who designed an interrupter gear that prevented a machine-gun from firing when a propeller blade passed in front of the barrel. The German LVG CVI had a forward-firing gun to the right of the engine, as well as a rear-cockpit gun, and a bombing capability. It was one of the most versatile aircraft of the war.

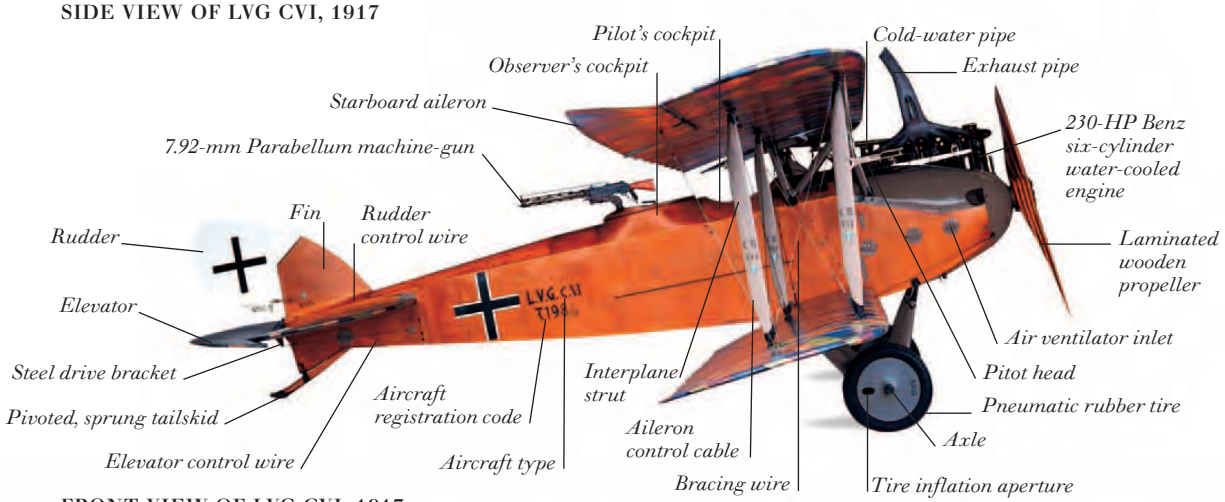
PORT WINGS FROM A BE 2B



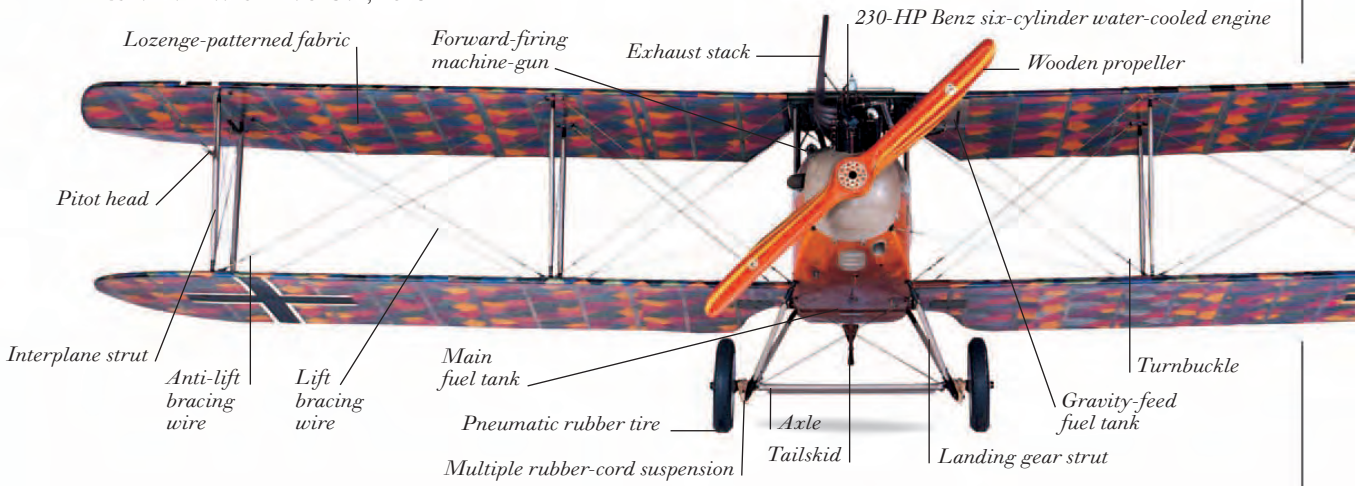
BE 2B, 1914

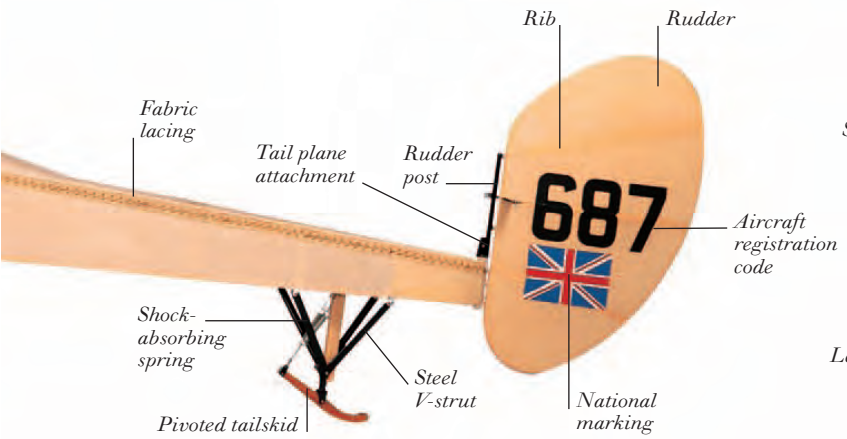


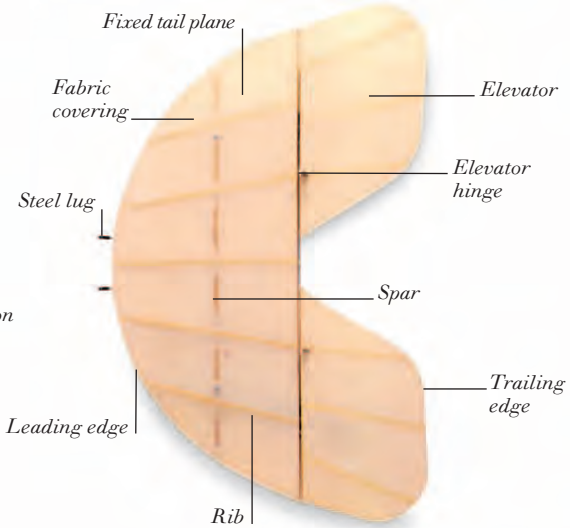
SIDE VIEW OF LVG CVI, 1917



FRONT VIEW OF LVG CVI, 1917





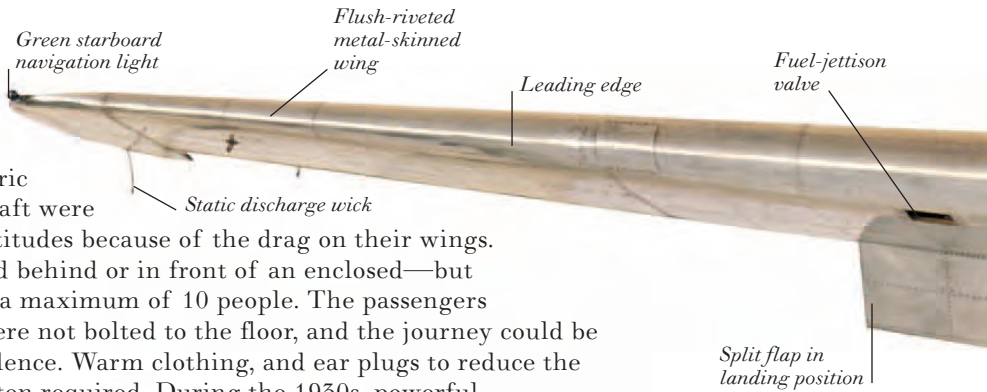


HORIZONTAL TAIL OF A BE 2B

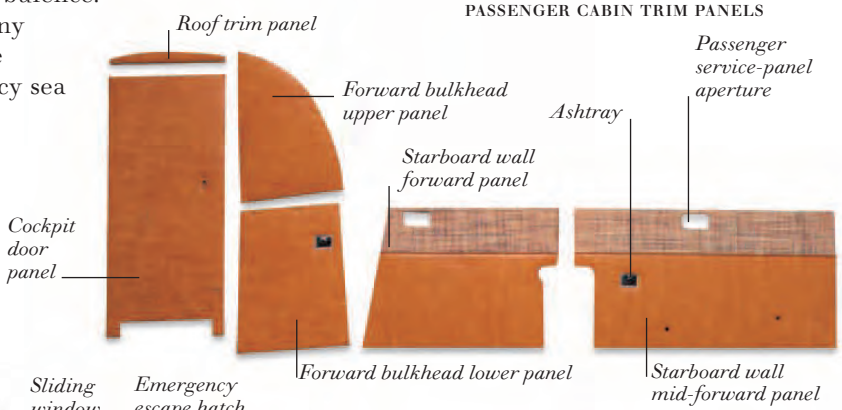
Early passenger aircraft

UNTIL THE 1930s, most passenger aircraft were biplanes, with two pairs of wings and a wooden or metal framework covered with fabric or, sometimes, plywood. Such aircraft were restricted to low speeds and low altitudes because of the drag on their wings. Many had an open cockpit, situated behind or in front of an enclosed—but unpressurized—cabin that carried a maximum of 10 people. The passengers usually sat in wicker chairs that were not bolted to the floor, and the journey could be bumpy when flying through turbulence. Warm clothing, and ear plugs to reduce the effects of prolonged noise, were often required. During the 1930s, powerful, streamlined, all-metal monoplanes, such as the Lockheed Electra shown here, became widespread. By 1939, the advent of pressurized cabins allowed fast flights at high altitudes, where there is less turbulence. Flying boats were still necessary on many routes until 1945 because of inadequate runways and the frequency of emergency sea landings. World War II, however, resulted in enough good runways being built for land-planes to become standard on all major airline routes.

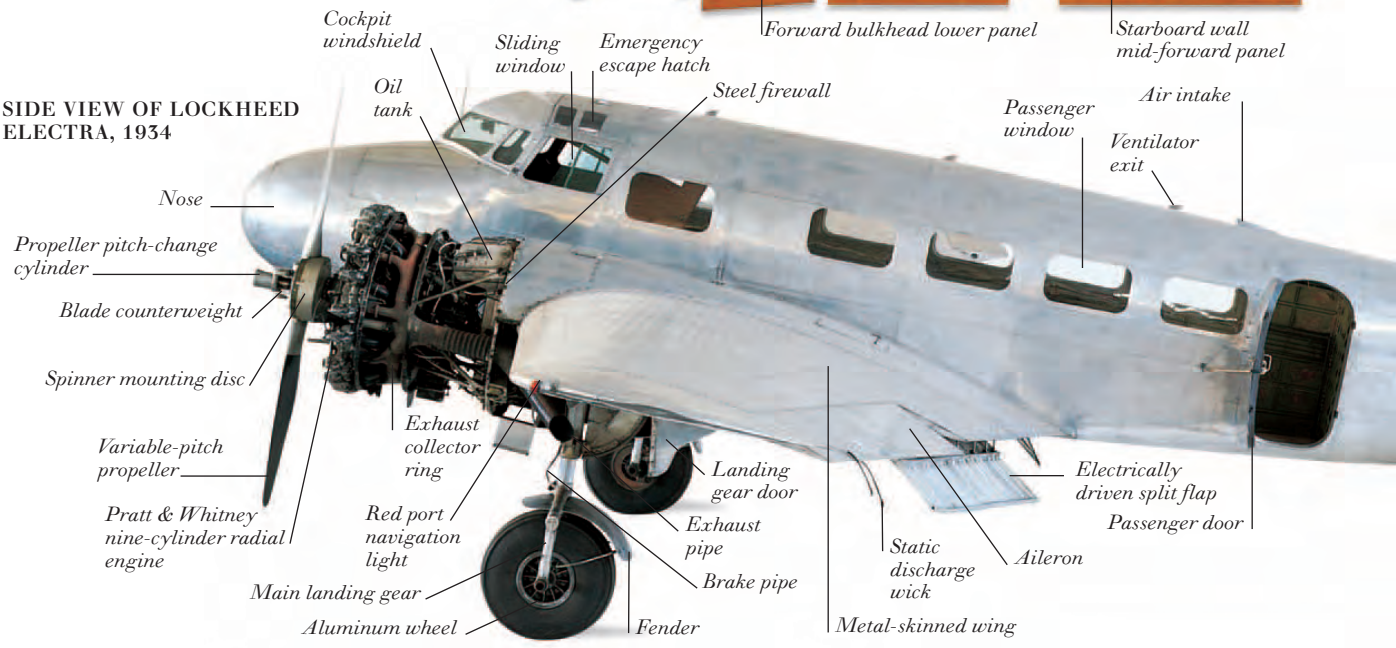
FRONT VIEW OF LOCKHEED ELECTRA, 1934

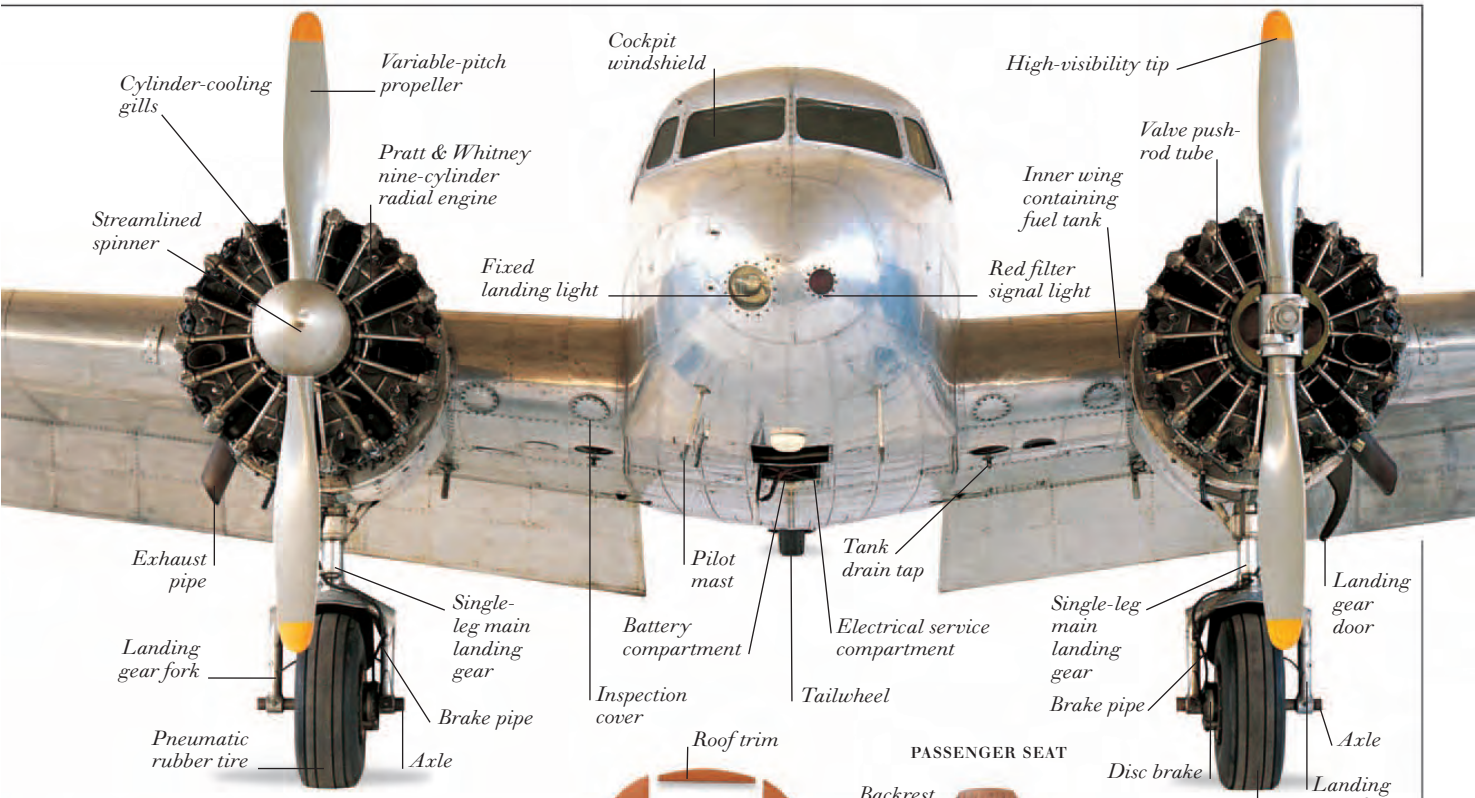


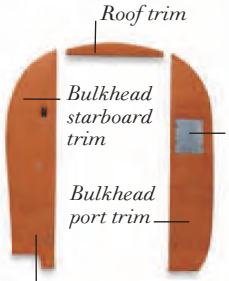
PASSENGER CABIN TRIM PANELS



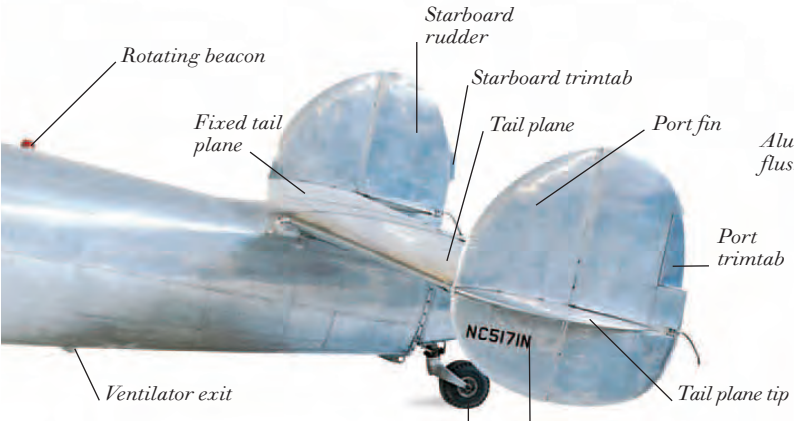
SIDE VIEW OF LOCKHEED ELECTRA, 1934



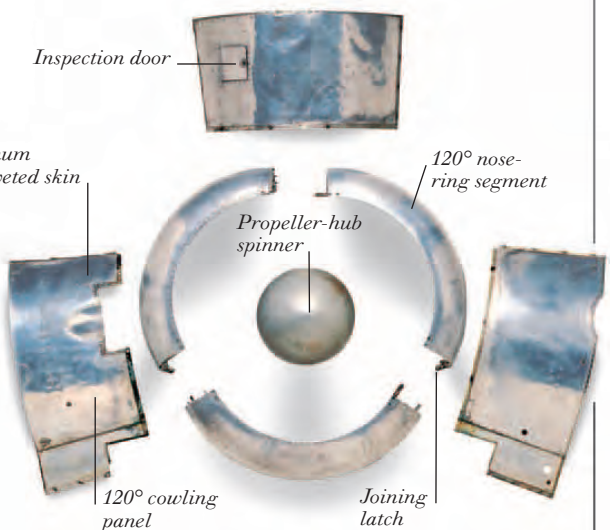




PASSENGER SEAT

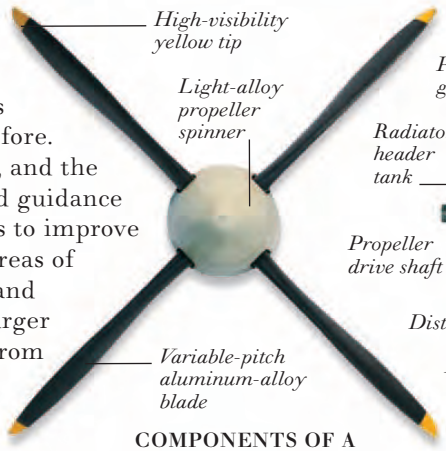


PORT ENGINE COWLINGS

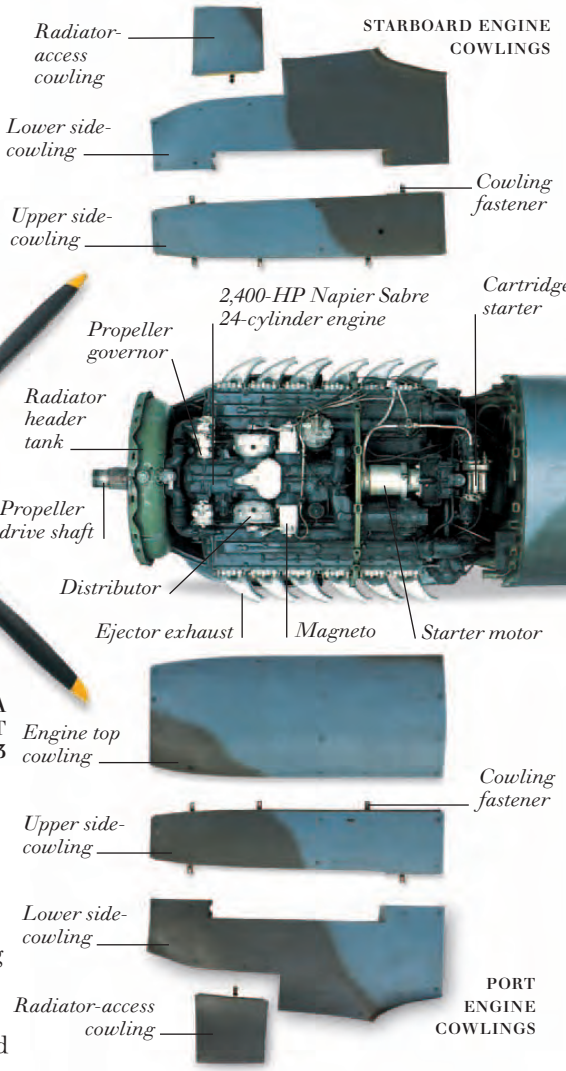


World War II aircraft

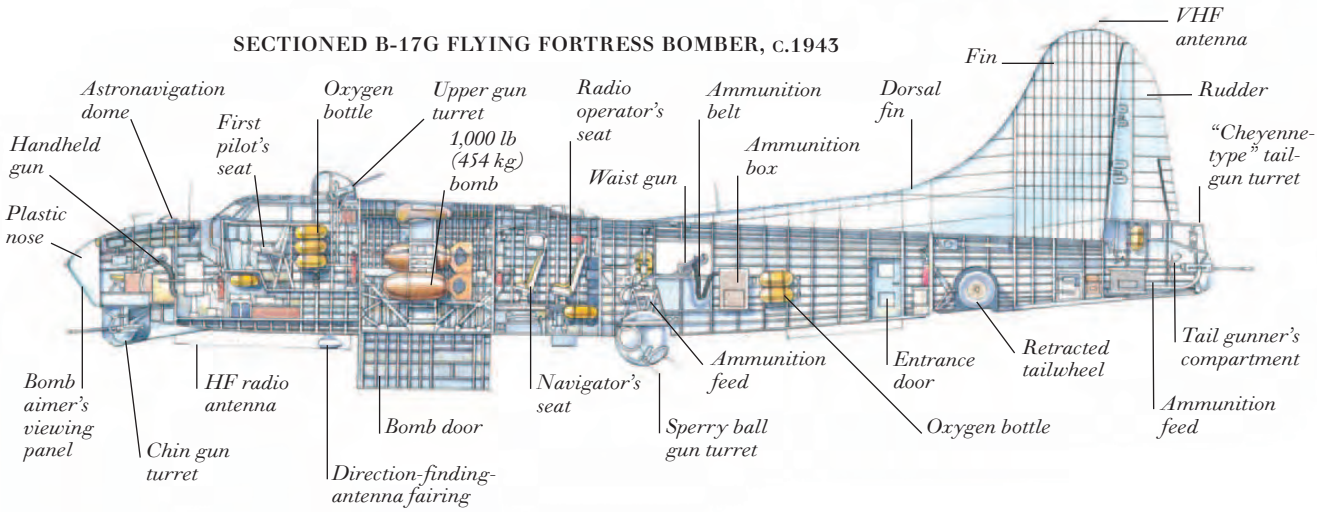
WHEN WORLD WAR II began in 1939, air forces had already replaced most of their fabric-skinned biplanes with all-metal, stressed-skin monoplanes. Aircraft played a far greater role in military operations during World War II than ever before. The wide range of aircraft duties, and the introduction of radar tracking and guidance systems, put pressure on designers to improve aircraft performance. The main areas of improvement were speed, range, and engine power. Bombers became larger and more powerful—converting from two to four engines—in order to carry a heavier bomb load; the US B-17 Flying Fortress could carry up to 6.8 tons (6.2 metric tons) of bombs over a distance of about 2,000 miles (3,200 km). Some aircraft increased their range by using drop tanks (fuel tanks that were jettisoned when empty to reduce drag). Fighters needed speed and manoeuvrability: the Hawker Tempest shown here had a maximum speed of 435 mph (700 km/h), and was one of the few Allied aircraft capable of catching the German jet-powered V1 "flying bomb." By 1944, Britain had introduced its first turbojet-powered aircraft, the Gloster Meteor fighter, and Germany had introduced the fastest fighter in the world, the turbojet-powered Me 262, which had a maximum speed of 540 mph (868 km/h).



COMPONENTS OF A HAWKER TEMPEST MARK V, C.1943

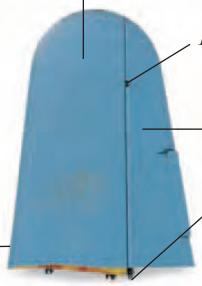


SECTIONED B-17G FLYING FORTRESS BOMBER, C.1943



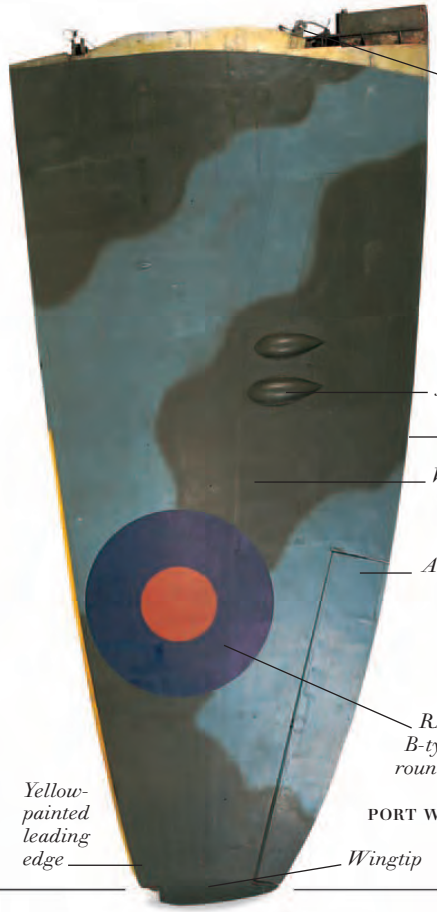
PORT WING UNDERSIDE

Flap
Landing gear door
Cockpit starboard access panel
Wing front fillet panel
Wing rear fillet panel
Wing fillet panel



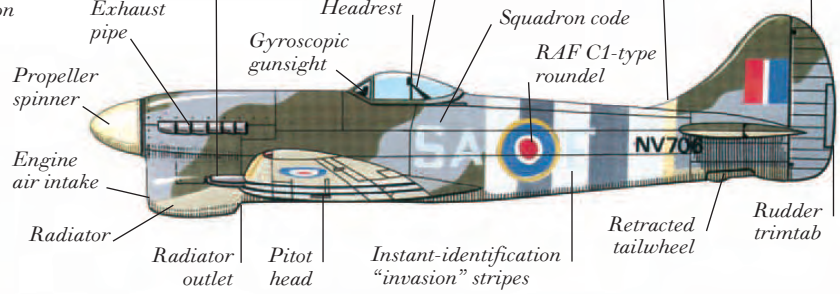
Starboard tail plane
Elevator hinge
Starboard elevator
Elevator control rod
Leading edge

Canopy rail
Seat pan
Harness strap
FUSELAGE
Canopy rail
VHF radio whip antenna
Fin
Tail fairing
Trimtab operating rod
Rudder
Dorsal fin
Tail plane root
Tail band
Flat, bulletproof windshield
Armored seat back
Gyroscopic gunsight
Plastic cockpit canopy
RAF C1-type roundel
Cockpit front belly panel
Cockpit center belly panel
Cockpit rear belly panel
Tail plane front attachment bracket
Tail plane rear attachment bracket
Port elevator trimtab
Trailing edge
Camouflage
Port tail plane
TAIL



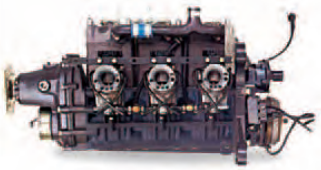
Rear spar trunnion
Wing fillet panel
Wing front fillet panel
Wing rear fillet panel
Outboard ammunition-feed blister
Cockpit port access panel
Trailing edge
Wing upper surface
Aileron
RAF B-type roundel
Yellow-painted leading edge
Wingtip
PORT WING

HAWKER TEMPEST MARK V FIGHTER, c.1943



Hispano Mark V 20-mm cannon
Armor-plated seat back
Rudder
Dorsal fin
Exhaust pipe
Headrest
Squadron code
Gyroscopic gunsight
RAF C1-type roundel
Propeller spinner
Engine air intake
Radiator
Radiator outlet
Pitot head
Instant-identification "invasion" stripes
Retracted tailwheel
Rudder trimtab

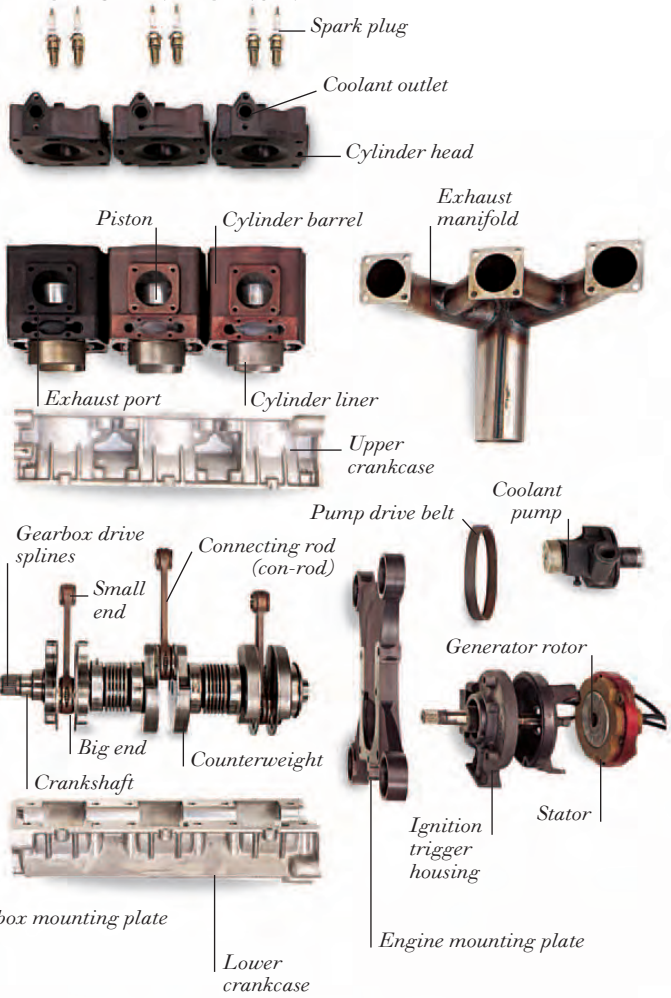
Modern piston aero-engines



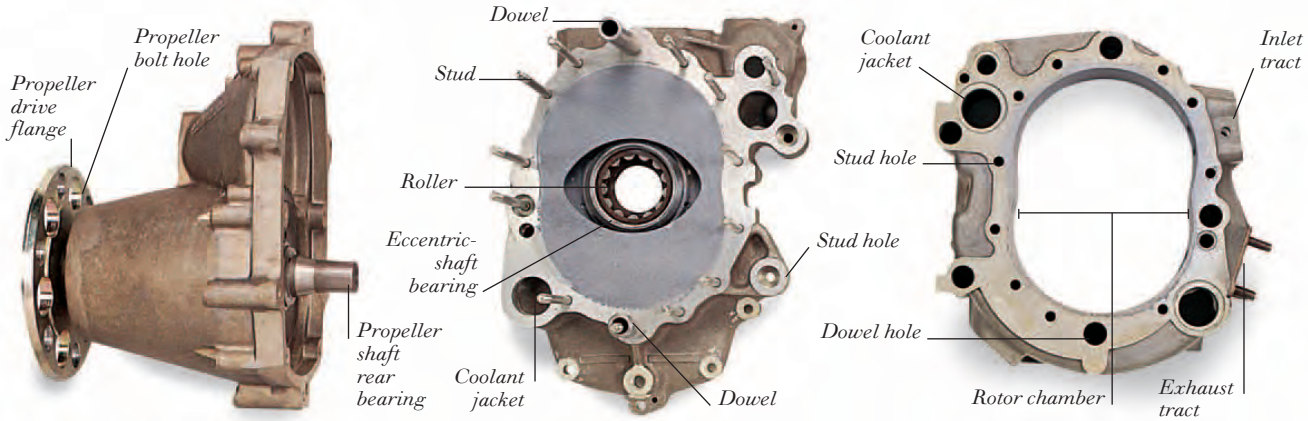
MID WEST TWO-STROKE, THREE-CYLNDER ENGINE

PISTON ENGINES today are used mainly to power the vast numbers of light aircraft and microlights, as well as crop-sprayers and crop-dusters, small helicopters, and fire-bombers (which dump water on large fires). Virtually all heavier aircraft are now powered by jet engines. Modern piston aero-engines work on the same basic principles as the engine used by the Wright brothers in the first powered flight in 1903. However, today's engines are more sophisticated than earlier engines. For example, modern aero-engines may use a two-stroke or a four-stroke combustion cycle; they may have from one to nine air- or water-cooled cylinders, which may be arranged horizontally, in-line, in V formation, or radially; and they may drive the aircraft's propeller either directly or through a reduction gearbox. One of the more unconventional types of modern aero-engine is the rotary engine shown here, which has a trilobate (three-sided) rotor spinning in a chamber shaped like a fat figure-eight.

MID WEST 75-HP TWO-STROKE, THREE-CYLINDER ENGINE

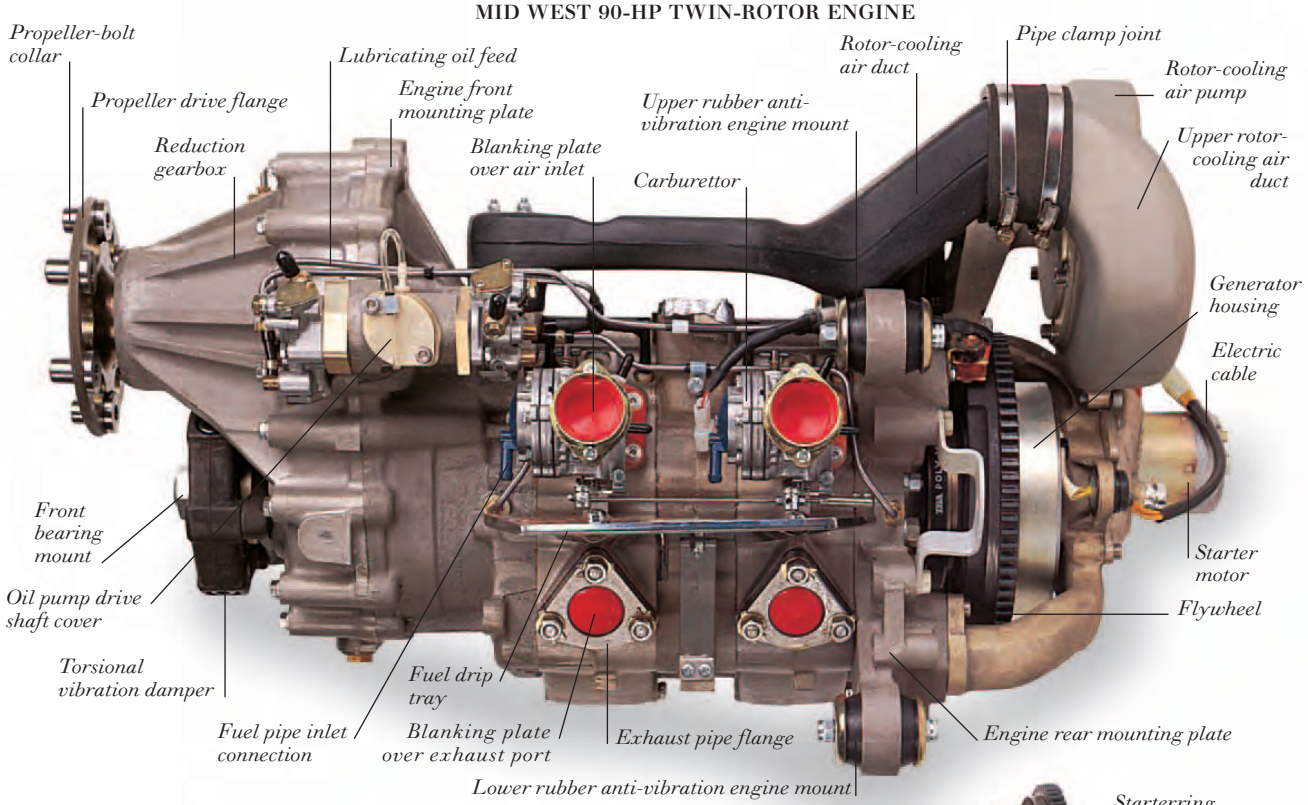


ROTOR AND HOUSINGS OF A MID WEST SINGLE-ROTOR ENGINE

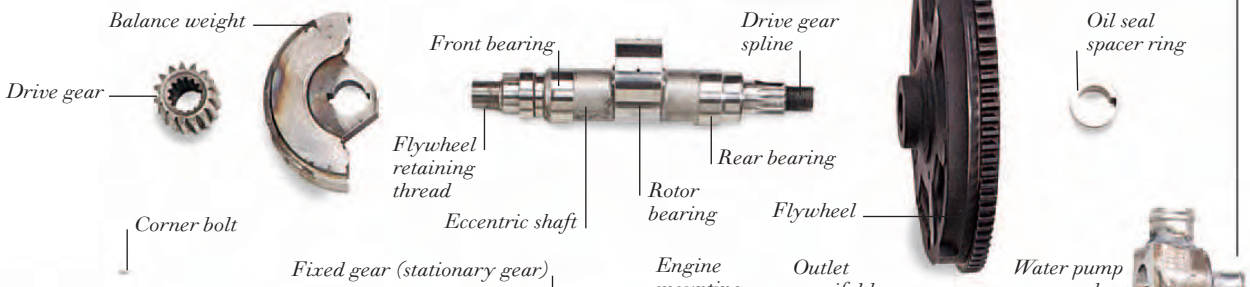


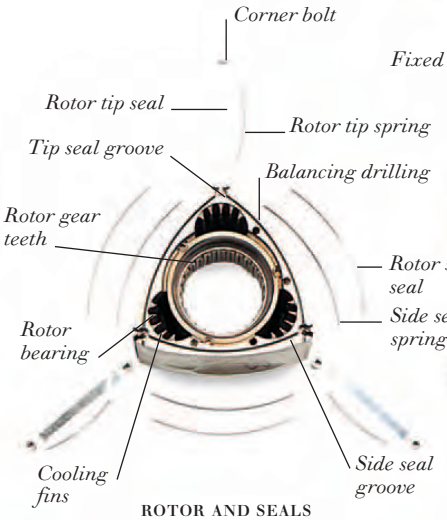
GEARBOX CASE | FRONT HOUSING (FRONT END-PLATE) | TROCHOID HOUSING

MID WEST 90-HP TWIN-ROTOR ENGINE

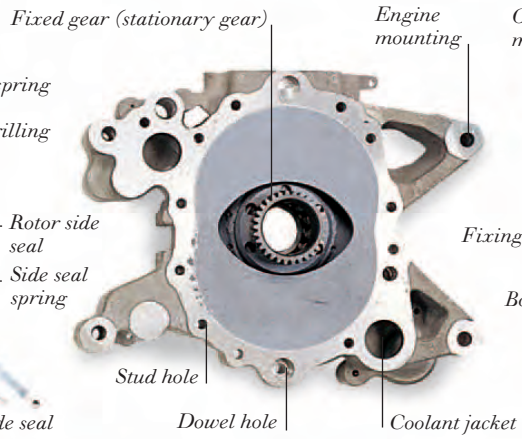


OUTPUT SHAFT OF A MID WEST ROTARY ENGINE

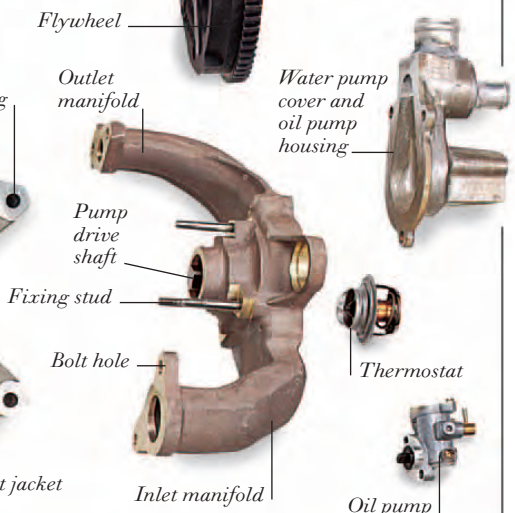




ROTOR AND SEALS



REAR HOUSING (REAR END-PLATE)

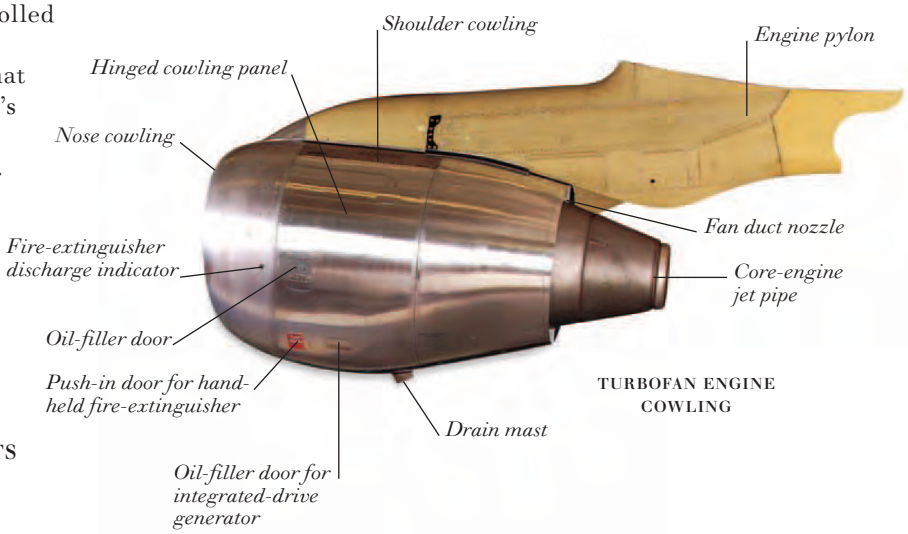


WATER PUMP HOUSING

Modern jetliners 1

BAE-146 JETLINER

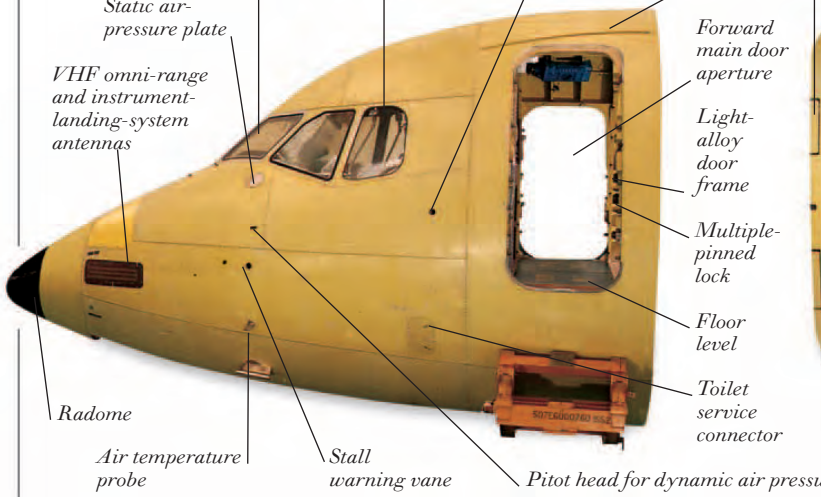
MODERN JETLINERS HAVE ENABLED ordinary people to travel to places where once only the wealthy could afford to go. Compared with the first jetliners (which were introduced in the 1940s), modern ones are much quieter, burn fuel more efficiently, and produce less air pollution. These advances are largely due to the replacement of turbojet engines with turbofan engines (see pp. 418-419). The greater power of turbofan engines at low speeds enables modern jetliners to carry more fuel and passengers than turbojet aircraft; a modern Boeing 747-400 (popularly known as a "jumbo jet") can fly 400 people for 8,500 miles (13,700 km) without needing to refuel. Jetliners fly at high altitudes, typically cruising at 26,000-36,000 ft (8000-11,000 m), where they can use fuel efficiently and usually avoid bad weather. The pilot always controls the aircraft during takeoff and landing, but at other times the aircraft is usually controlled by an autopilot. Autopilots are complex on-board mechanisms that detect deviations from an aircraft's route and make appropriate adjustments to the flight controls. Flight decks are also equipped with radars that warn pilots of approaching hazards, such as mountain ranges, bad weather, and other aircraft.



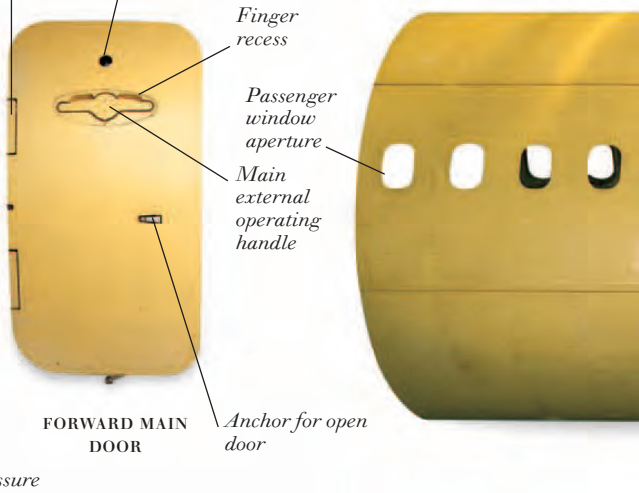
TURBOFAN ENGINE COWLING

STRUCTURAL COMPONENTS OF A BAE-146 JETLINER

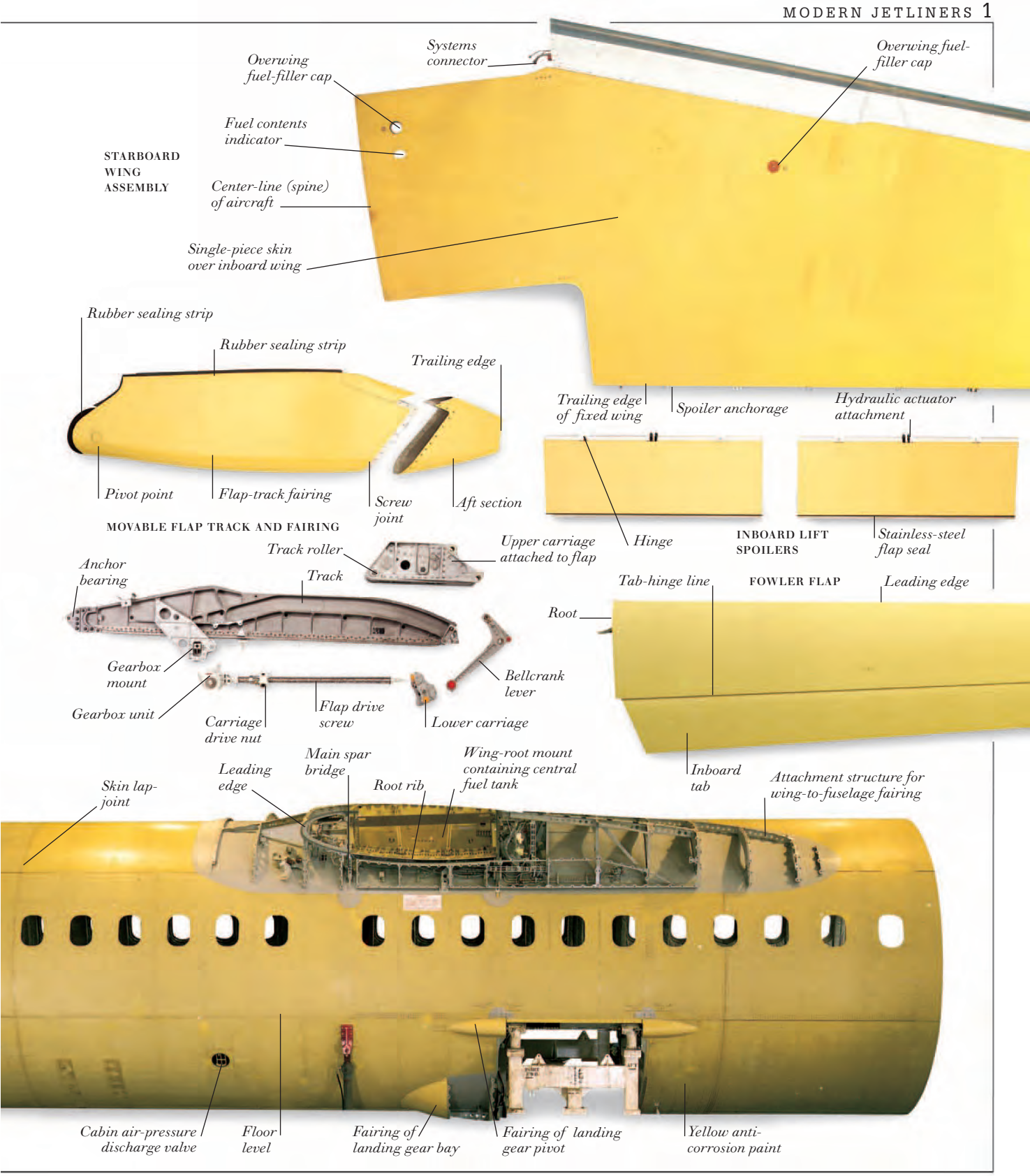
FUSELAGE NOSE-SECTION



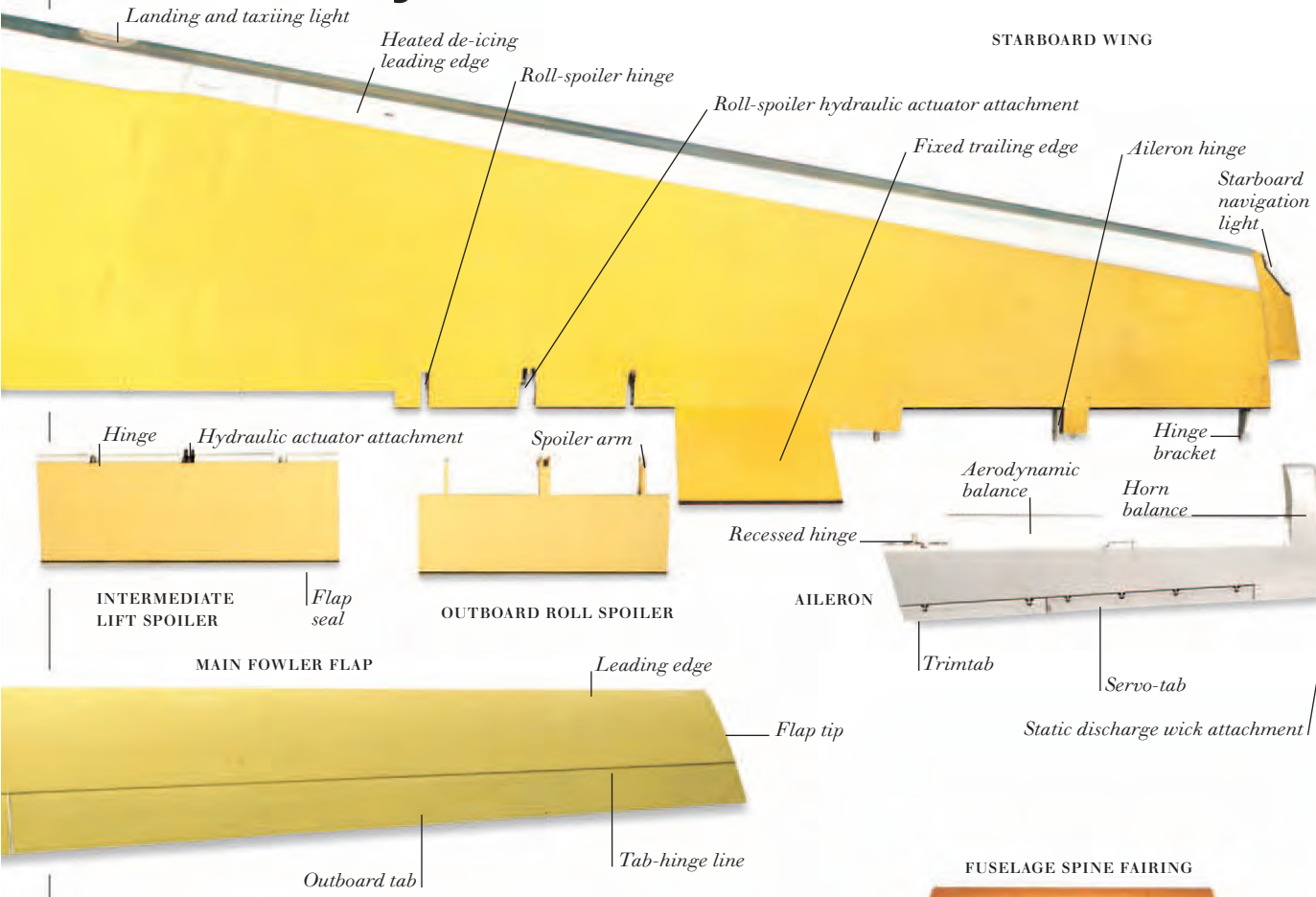
FUSELAGE MID-SECTION

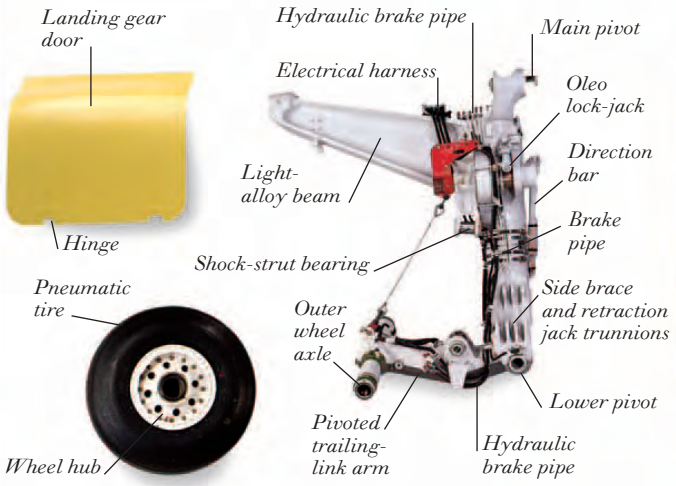


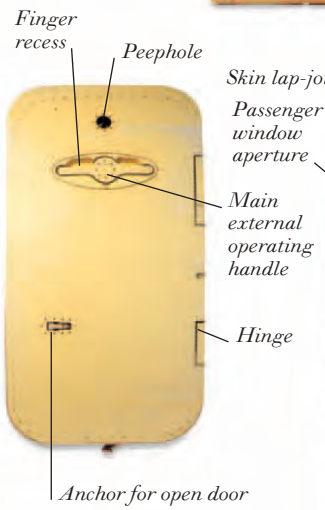
FORWARD MAIN DOOR

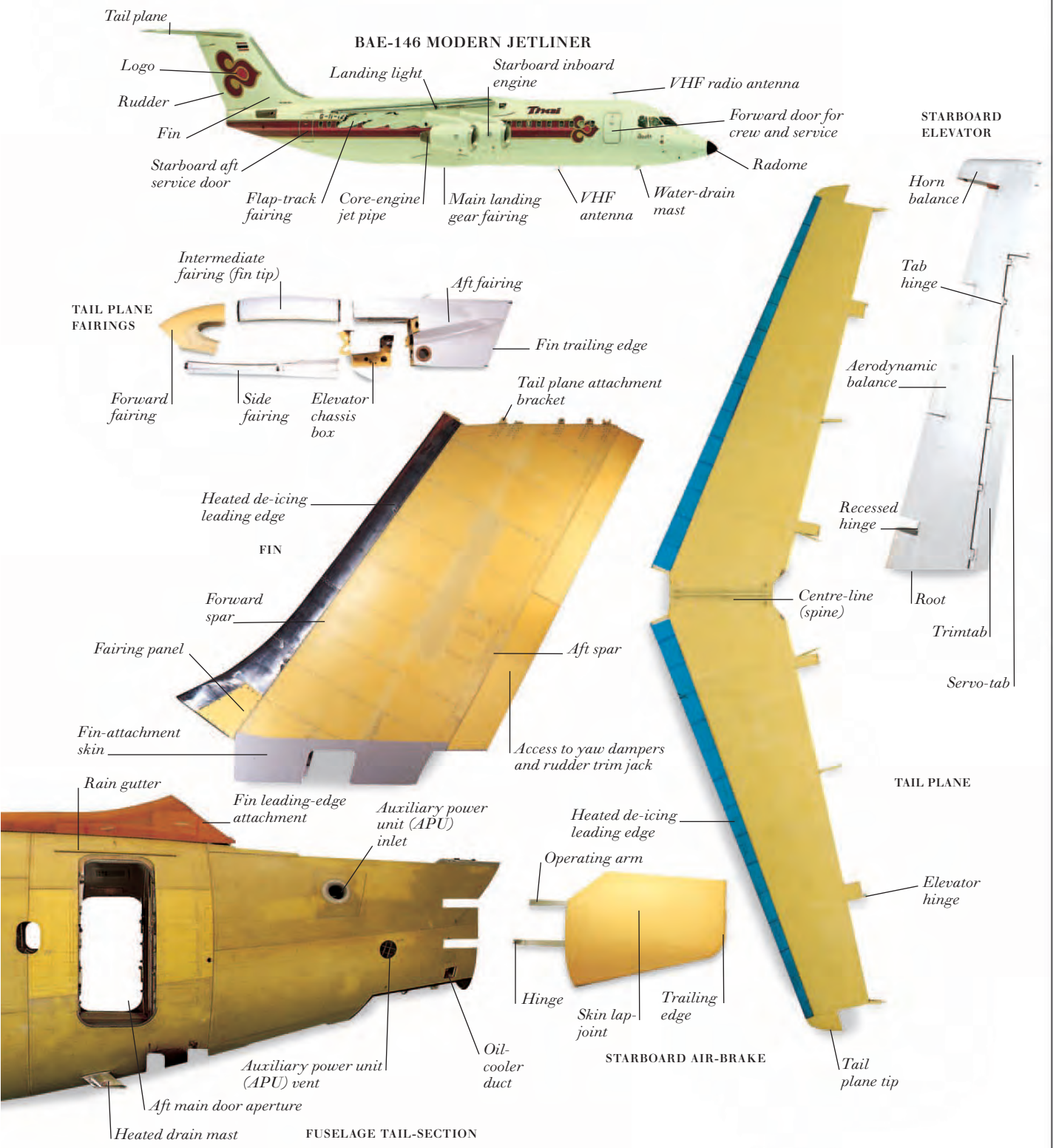

STARBOARD WING ASSEMBLY
Overwing fuel-filler cap
Systems connector
Overwing fuel-filler cap
Fuel contents indicator
Center-line (spine) of aircraft
Single-piece skin over inboard wing
Rubber sealing strip
Rubber sealing strip
Trailing edge
Pivot point
Flap-track fairing
Screw joint
Aft section
MOVABLE FLAP TRACK AND FAIRING
Trailing edge of fixed wing
Spoiler anchorage
Hydraulic actuator attachment
Hinge
INBOARD LIFT SPOILERS
Stainless-steel flap seal
Track roller
Upper carriage attached to flap
Anchor bearing
Track
Gearbox mount
Bellcrank lever
Gearbox unit
Carriage drive nut
Flap drive screw
Lower carriage
Tab-hinge line
FOWLER FLAP
Leading edge
Root
Inboard tab
Skin lap-joint
Leading edge
Main spar bridge
Root rib
Wing-root mount containing central fuel tank
Attachment structure for wing-to-fuselage fairing
Cabin air-pressure discharge valve
Floor level
Fairing of landing gear bay
Fairing of landing gear pivot
Yellow anti-corrosion paint

Modern jetliners 2

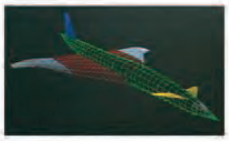






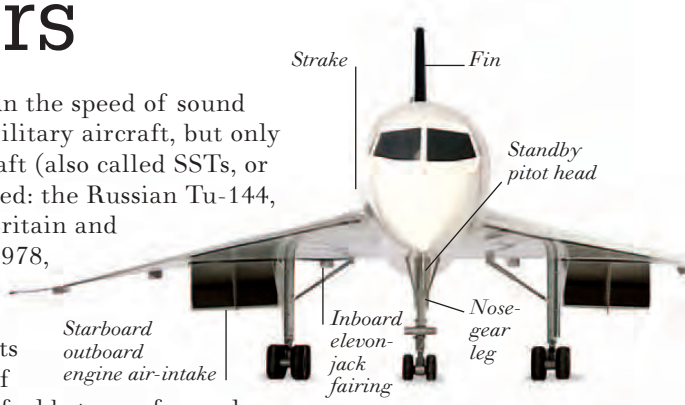

BAE-146 MODERN JETLINER
Tail plane
Logo
Rudder
Fin
Starboard aft service door
Landing light
Starboard inboard engine
VHF radio antenna
Forward door for crew and service
Radome
Flap-track fairing
Core-engine jet pipe
Main landing gear fairing
VHF antenna
Water-drain mast
TAIL PLANE FAIRINGS
Intermediate fairing (fin tip)
Aft fairing
Fin trailing edge
Forward fairing
Side fairing
Elevator chassis box
Tail plane attachment bracket
FIN
Heated de-icing leading edge
Forward spar
Fairing panel
Aft spar
Fin-attachment skin
Access to yaw dampers and rudder trim jack
Rain gutter
Fin leading-edge attachment
Auxiliary power unit (APU) inlet
Auxiliary power unit (APU) vent
Oil-cooler duct
Aft main door aperture
Heated drain mast
FUSELAGE TAIL-SECTION
STARBOARD ELEVATOR
Horn balance
Tab hinge
Aerodynamic balance
Recessed hinge
Root
Trimtab
Servo-tab
Centre-line (spine)
TAIL PLANE
Heated de-icing leading edge
Elevator hinge
Operating arm
Hinge
Skin lap-joint
Trailing edge
STARBOARD AIR-BRAKE
Tail plane tip

Supersonic jetliners



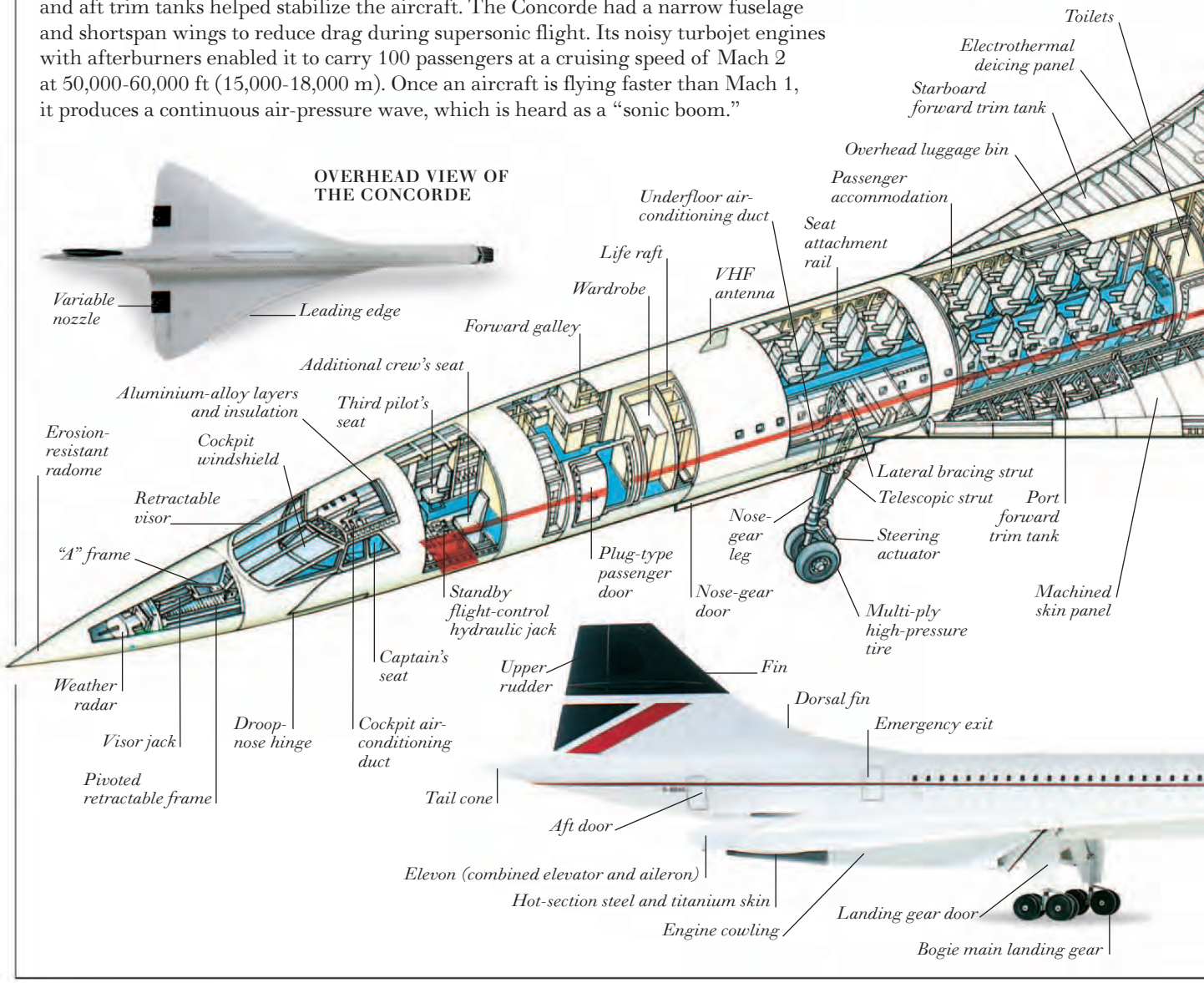
COMPUTER-DESIGNED SST

SUPERSONIC AIRCRAFT FLY FASTER than the speed of sound (Mach 1). There are many supersonic military aircraft, but only two supersonic passenger-carrying aircraft (also called SSTs, or supersonic transports) have been produced: the Russian Tu-144, and the Concorde, produced jointly by Britain and France. The Tu-144 was withdrawn in 1978, after only seven months in service. The Concorde remained in service from 1976 until 2003, with a break for modifications from July 2000 until October 2001. Its features included a droop nose, which lowered during takeoff and landing to aid visibility from the cockpit; the pumping of fuel between forward and aft trim tanks helped stabilize the aircraft. The Concorde had a narrow fuselage and shortspan wings to reduce drag during supersonic flight. Its noisy turbojet engines with afterburners enabled it to carry 100 passengers at a cruising speed of Mach 2 at 50,000-60,000 ft (15,000-18,000 m). Once an aircraft is flying faster than Mach 1, it produces a continuous air-pressure wave, which is heard as a "sonic boom."

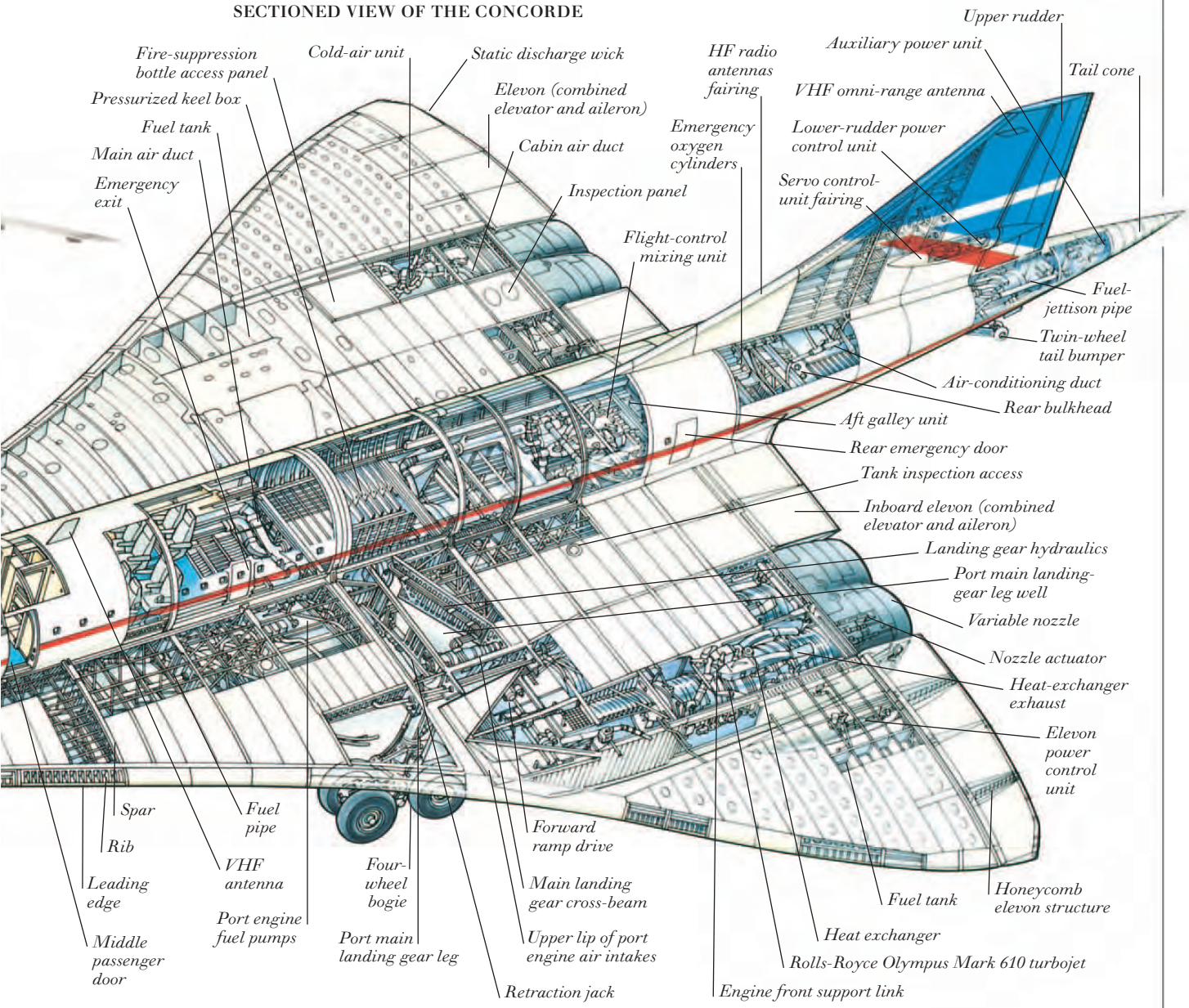


FRONT OF THE CONCORDE

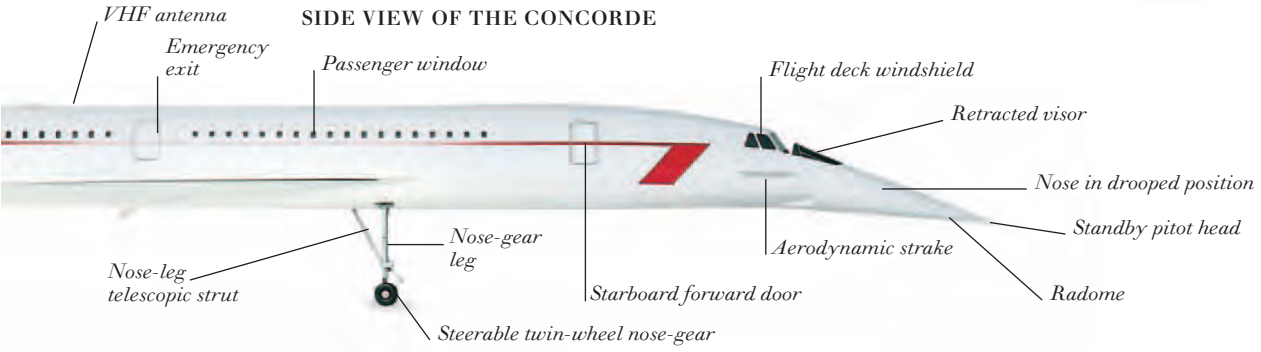
OVERHEAD VIEW OF THE CONCORDE



SECTIONED VIEW OF THE CONCORDE



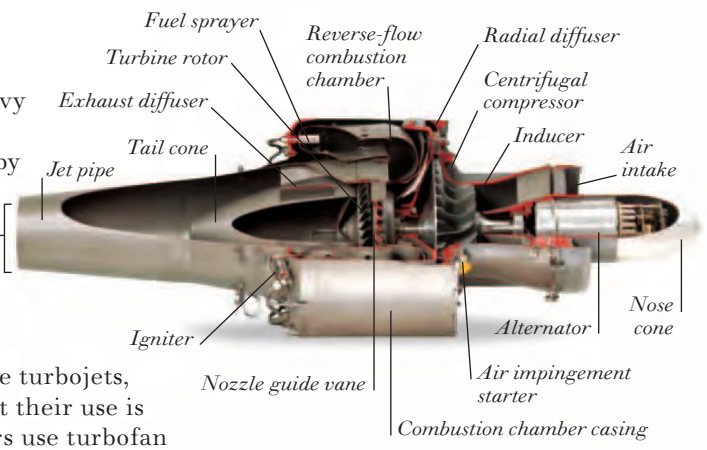
SIDE VIEW OF THE CONCORDE

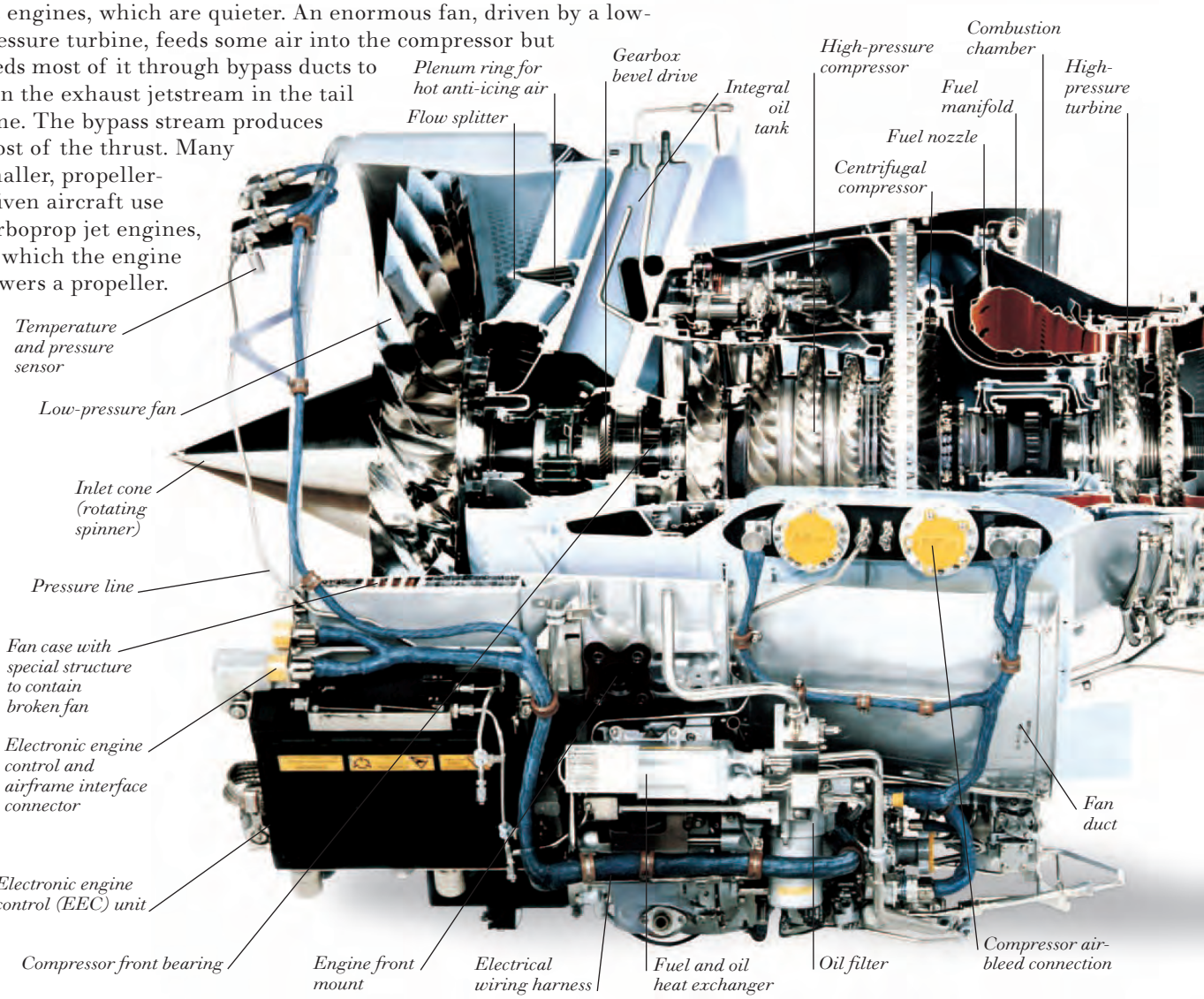


Jet engines

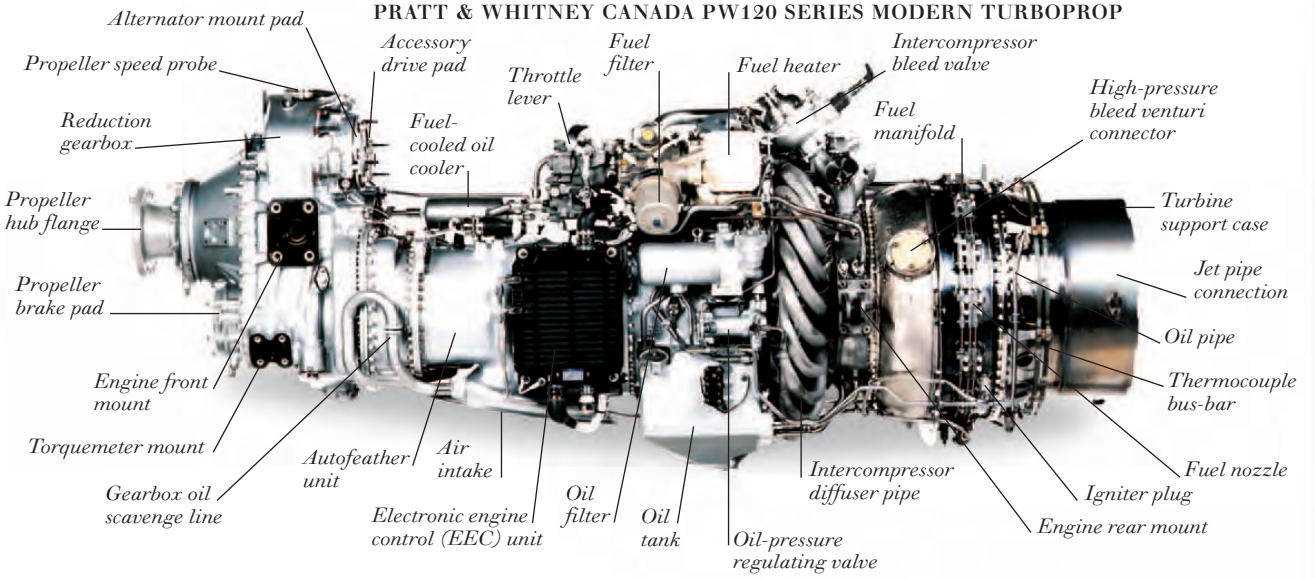
JET ENGINES ARE USED BY MOST MILITARY and heavy aircraft, and by many helicopters. The simplest type of jet engine, or gas turbine, is the turbojet. It works by continuously burning a mixture of fuel and air in a combustion chamber to produce a jet of hot exhaust gas that is expelled through a nozzle to produce thrust. The hot gas also spins turbine blades, which, in turn, spin the blades of an air compressor; the compressor forces air into the combustion chamber. Many of the fastest aircraft use turbojets, with additional booster units called afterburners, but their use is restricted by their high noise emission. Most jetliners use turbofan jet engines, which are quieter. An enormous fan, driven by a low-pressure turbine, feeds some air into the compressor but feeds most of it through bypass ducts to join the exhaust jetstream in the tail cone. The bypass stream produces most of the thrust. Many smaller, propeller-driven aircraft use turboprop jet engines, in which the engine powers a propeller.

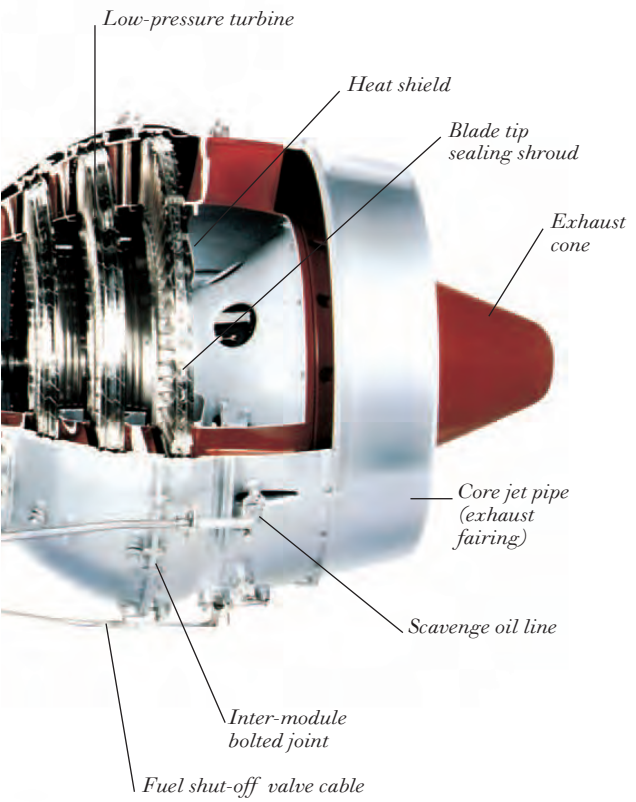
NPT 301 MODERN TURBOJET





PRATT & WHITNEY CANADA PW120 SERIES MODERN TURBOPROP

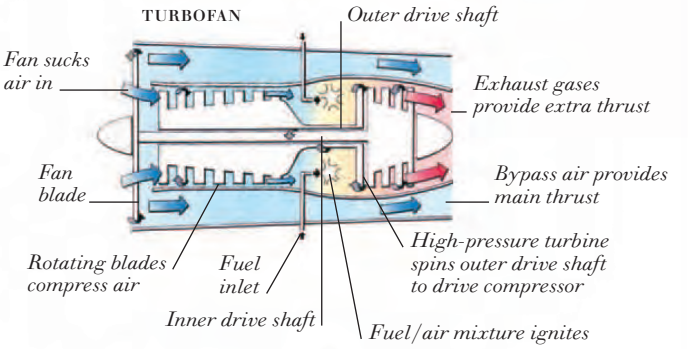




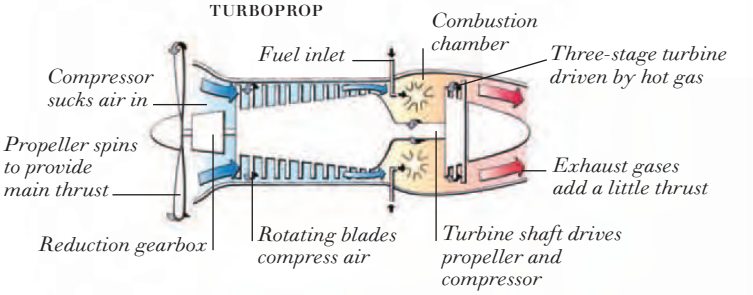
SECTIONED PRATT & WHITNEY CANADA PW305 MODERN TURBOFAN

HOW JET ENGINES WORK

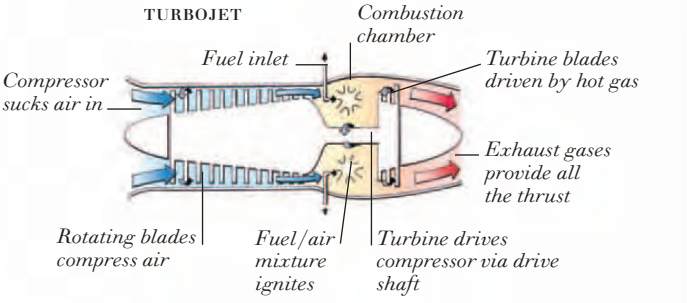
TURBOFAN



TURBOPROP



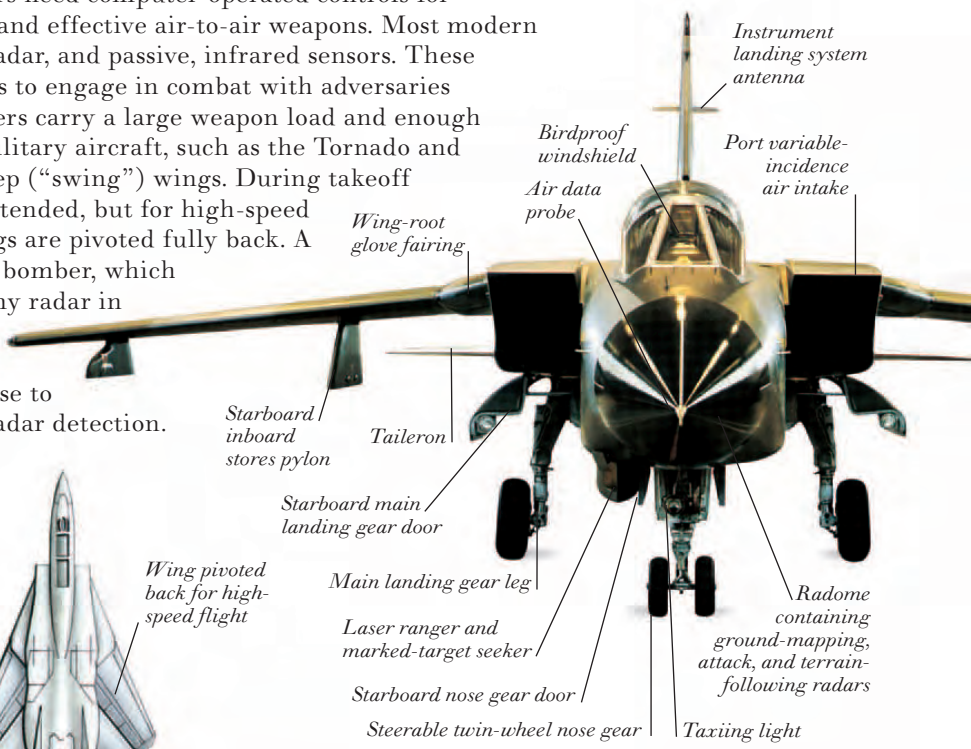
TURBOJET

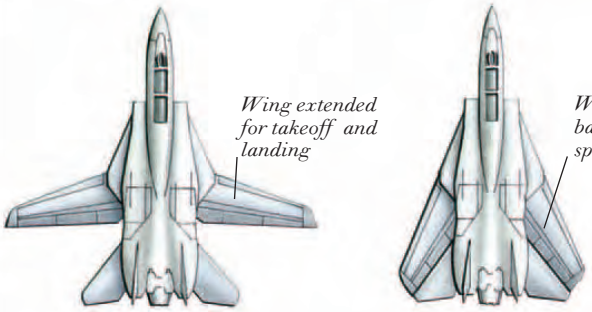


Modern military aircraft

MODERN MILITARY AIRCRAFT ARE AMONG THE MOST SOPHISTICATED and expensive products of the 21st century. Fighters need computer-operated controls for maneuverability, powerful engines, and effective air-to-air weapons. Most modern fighters also have guided missiles, radar, and passive, infrared sensors. These developments enable today's fighters to engage in combat with adversaries that are outside visual range. Bombers carry a large weapon load and enough fuel for long-range flights. A few military aircraft, such as the Tornado and the F-14 Tomcat, have variable-sweep ("swing") wings. During takeoff and landing their wings are fully extended, but for high-speed flight and low-level attacks the wings are pivoted fully back. A recent development is the "stealth" bomber, which is designed to absorb or deflect enemy radar in order to remain undetected. Earlier bombers, such as the Tornado, use terrain-following radars to fly so close to the ground that they avoid enemy radar detection.

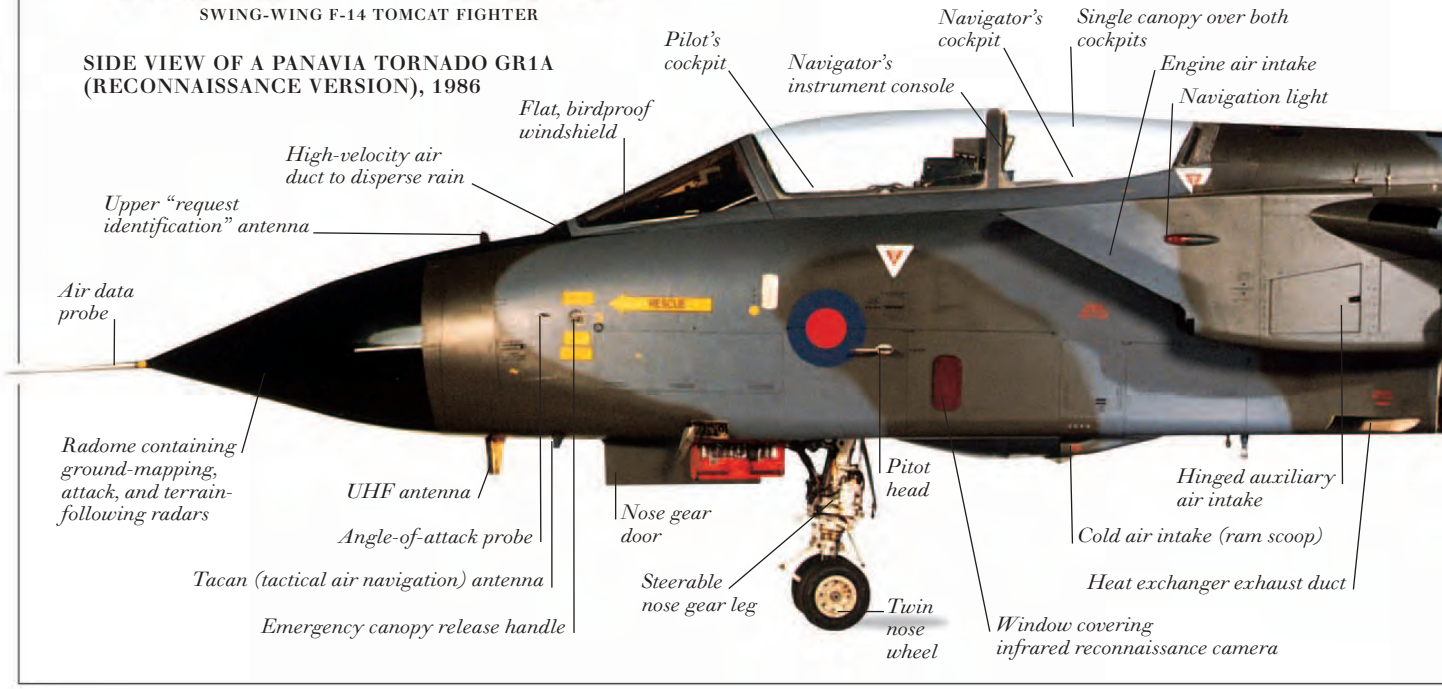
FRONT VIEW OF A PANAVIA TORNADO



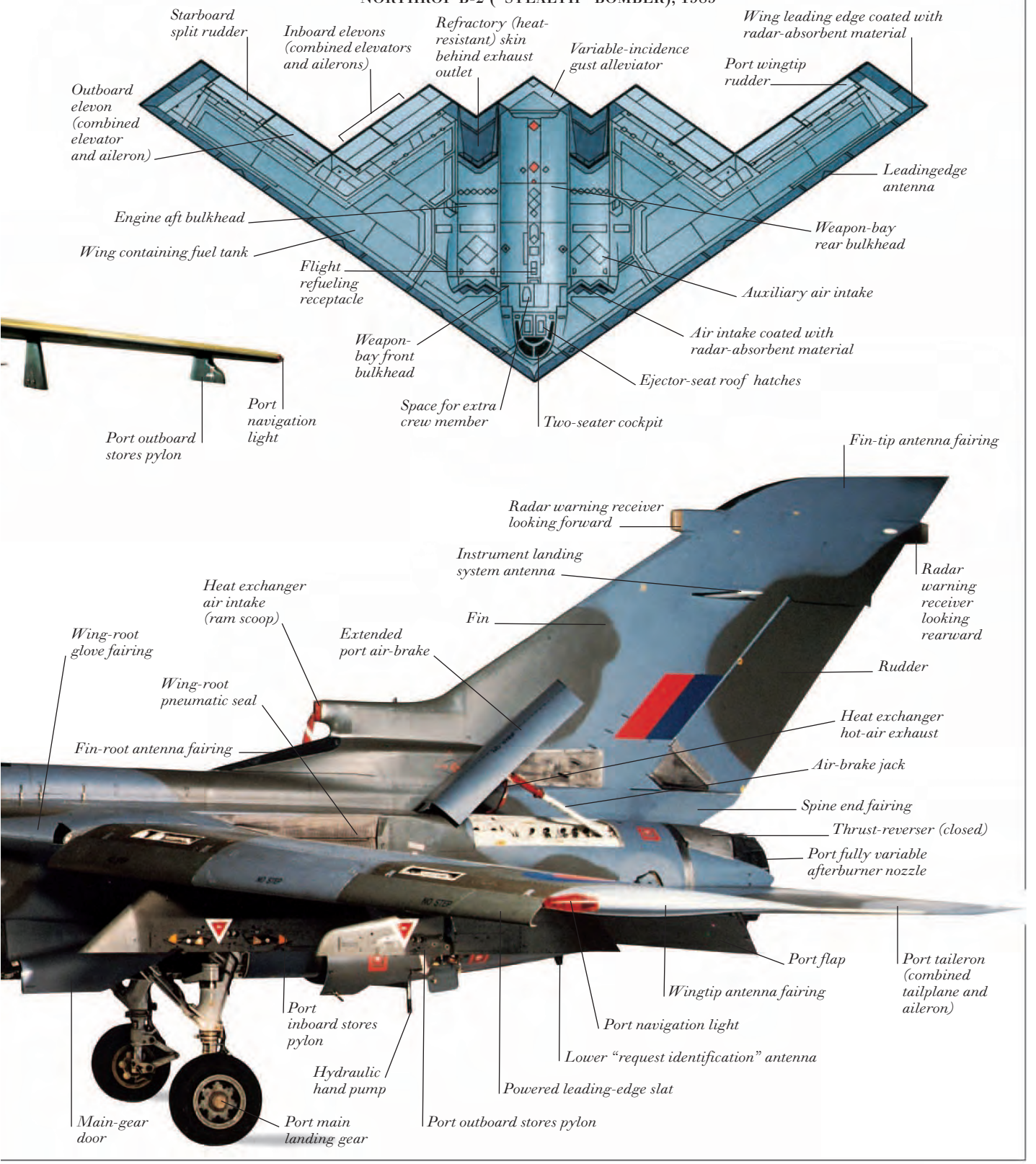


SWING-WING F-14 TOMCAT FIGHTER

SIDE VIEW OF A PANAVIA TORNADO GR1A (RECONNAISSANCE VERSION), 1986



NORTHROP B-2 ("STEALTH" BOMBER), 1989



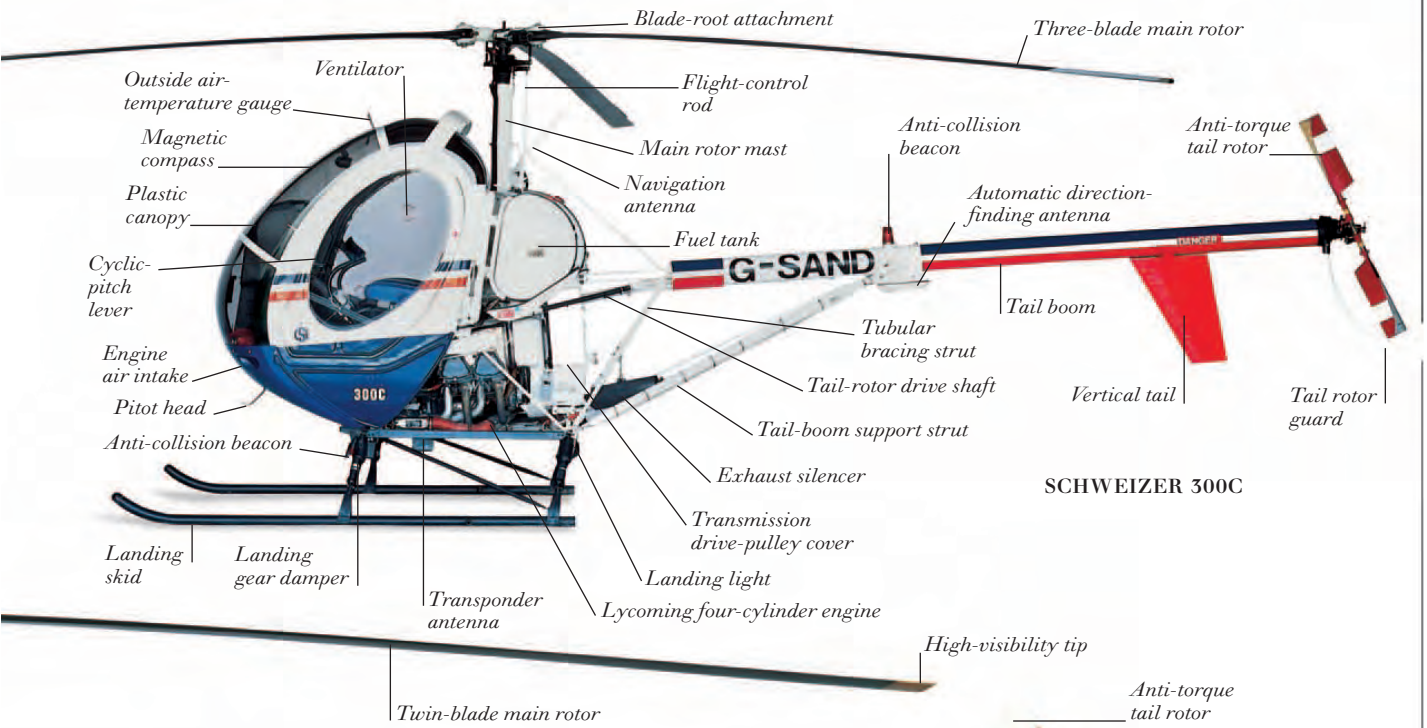
Helicopters

BELL 47G-3B1

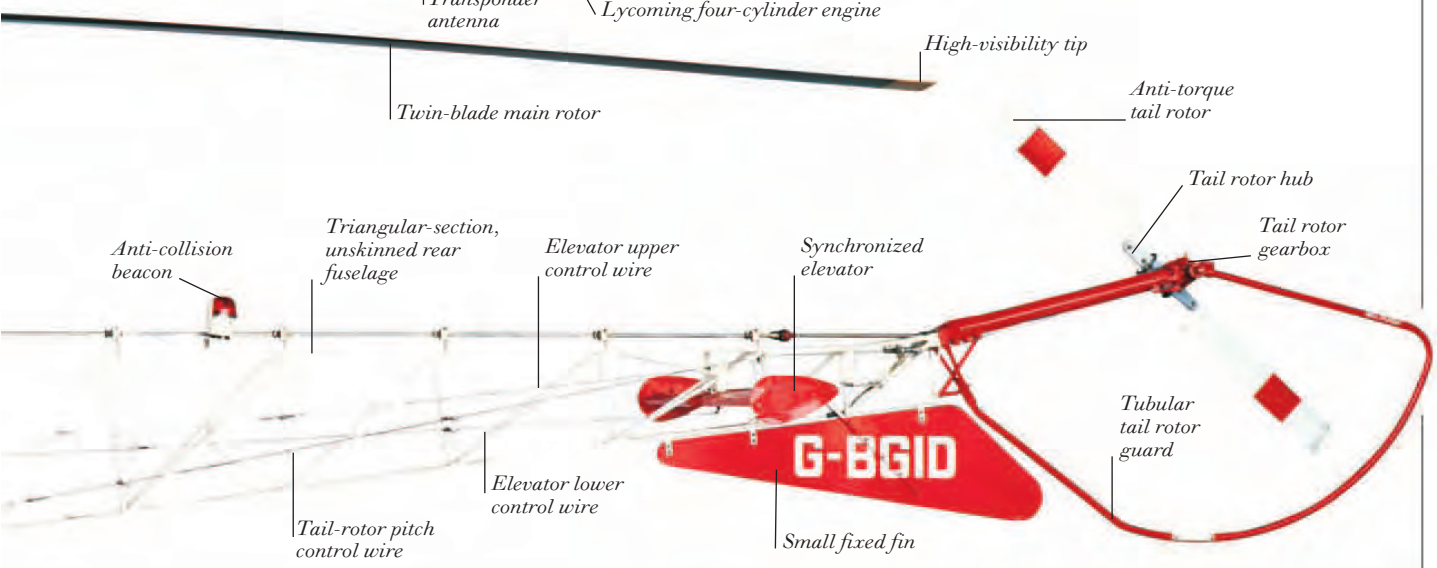
HELICOPTERS USE ROTATING BLADES for lift, propulsion, and steering. The first machine to achieve sustained, controlled flight using rotating blades was the autogiro built in the 1920s by the Spaniard Juan de la Cierva. His machine had unpowered blades above the fuselage that relied on the flow of air to rotate them and provide lift as the autogiro was driven forward by a conventional propeller. Then, in 1939, the Russian-born American Igor Sikorsky produced his VS-300, the forerunner of modern helicopters. Its engine-driven blades provided lift, propulsion, and steering. It could take off vertically, hover, and fly in any direction, and had a tail rotor to prevent the helicopter body from spinning. The introduction of gas turbine jet engines to helicopters in 1955 produced quieter, safer, and more powerful machines. Because of their versatility in flight, helicopters are today used for many purposes, including crop spraying, traffic surveillance, and transporting crews to deep-sea oil rigs, as well as acting as gunships, air ambulances, and air taxis.

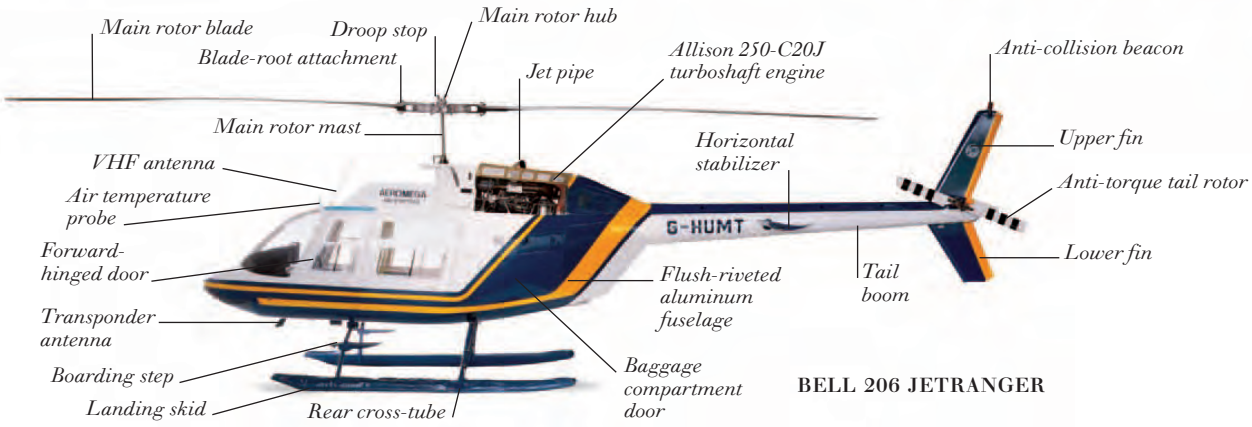
BELL 47G-3B1

Droop stop
Blade counterweight
Main rotor hub
Blade-root attachment
Main rotor mast
Stabilizer-bar weight
Direct-vision panel
Fuel vent pipe
Protective gaiter
Frameless plastic canopy
Fuel tank
Fuel tank cradle
Tail-rotor drive shaft
Exhaust pipe
Radio
Air intake pipe
Instrument panel
Electric fuel pump
Cyclic-pitch lever
Battery
Battery overspill
Electrical inverter
Pitot head
Breather pipe
Anti-collision beacon
Oil tank
Landing light
Carburetor hot-air intake pipe
Landing skid
Air filter
VHF omni-range antenna
Navigation light
Ground handling wheel
Valve-rocker cover
Ventilator
Electric power socket
Lycoming six-cylinder engine
Collective-pitch lever
Riveted light-alloy forward fuselage section



SCHWEIZER 300C

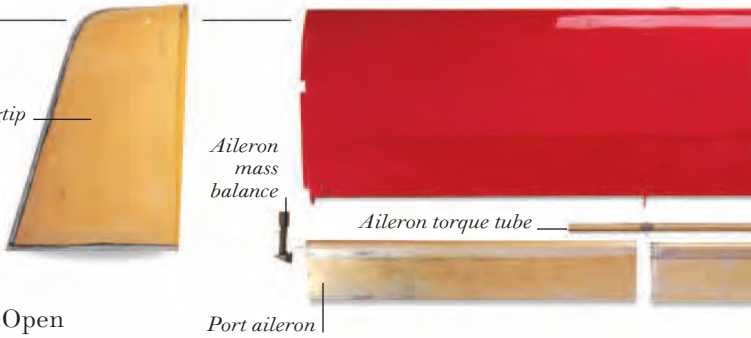


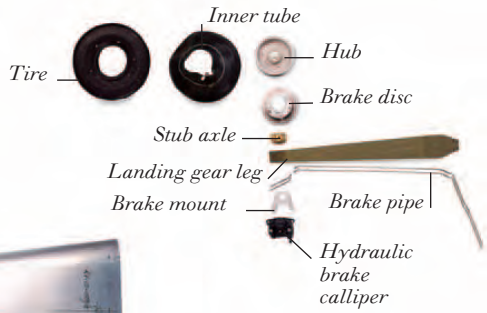


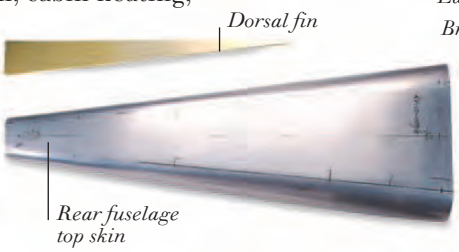
BELL 206 JETRANGER

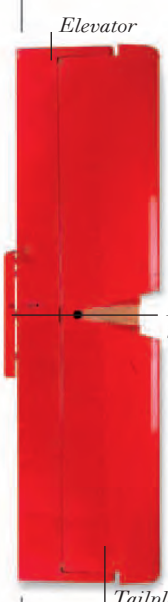
Light aircraft

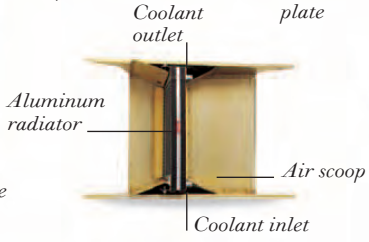
LIGHT AIRCRAFT, SUCH AS THE ARV SUPER 2 shown here, are small, lightweight, and of simple construction. More than a million have been built since World War I, mainly for recreational use by private owners. Virtually all light aircraft have piston engines, most of which are air-cooled, although some are liquid-cooled. Open cockpits, almost universal in the 1920s, have today been replaced by enclosed cabins. The cabins of high-wing aircraft have one or two doors, whereas those of low-wing aircraft usually have a sliding or hinged canopy. Most modern light aircraft are made of aluminum alloy, although some are made of wood or of fiber-reinforced materials. Light aircraft today also usually have navigational instruments, an electrical system, cabin heating, wheel brakes, and a two-way radio.

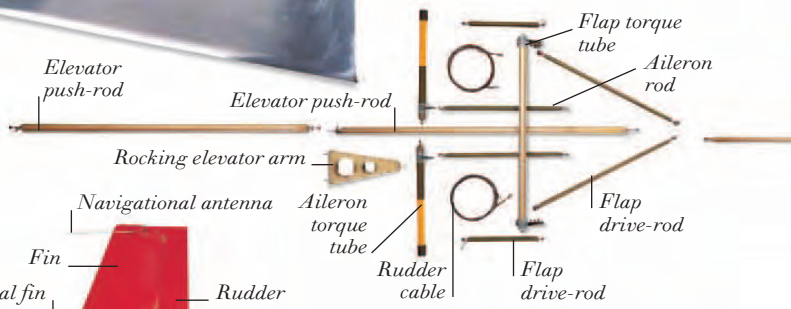


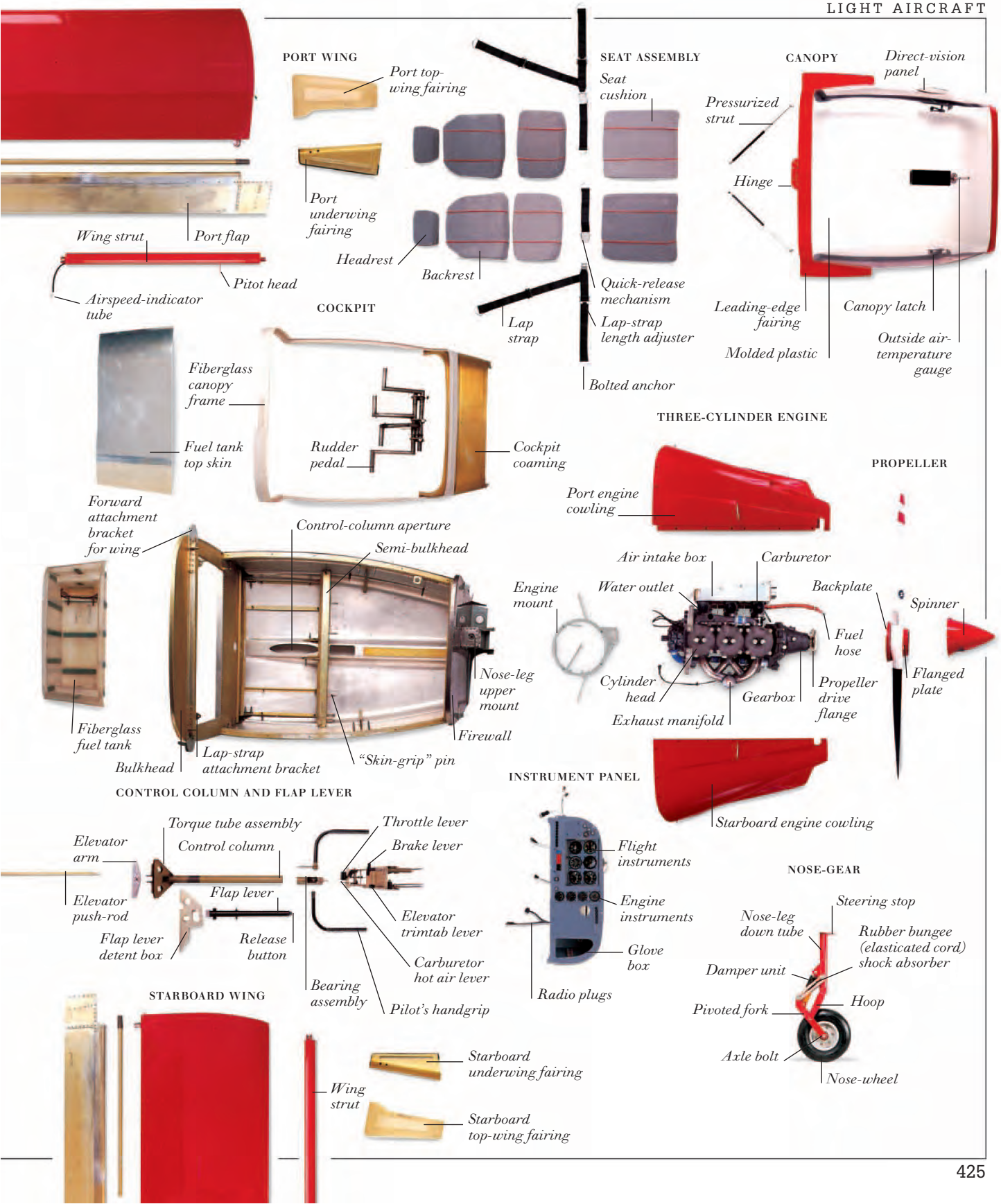











PORT WING
Port top-wing fairing
Port underwing fairing
Wing strut
Port flap
Pitot head
Airspeed-indicator tube
SEAT ASSEMBLY
Seat cushion
Headrest
Backrest
Lap strap
Quick-release mechanism
Lap-strap length adjuster
Bolted anchor
CANOPY
Direct-vision panel
Pressurized strut
Hinge
Leading-edge fairing
Molded plastic
Canopy latch
Outside air-temperature gauge
COCKPIT
Fiberglass canopy frame
Fuel tank top skin
Rudder pedal
Cockpit coaming
THREE-CYLINDER ENGINE
Port engine cowling
PROPELLER
Spinner
Flanged plate
Air intake box
Carburetor
Engine mount
Water outlet
Backplate
Fuel hose
Cylinder head
Gearbox
Propeller drive flange
Exhaust manifold
Forward attachment bracket for wing
Control-column aperture
Semi-bulkhead
Nose-leg upper mount
Fiberglass fuel tank
Bulkhead
Lap-strap attachment bracket
"Skin-grip" pin
Firewall
Starboard engine cowling
INSTRUMENT PANEL
Flight instruments
Engine instruments
Glove box
Radio plugs
CONTROL COLUMN AND FLAP LEVER
Torque tube assembly
Elevator arm
Control column
Elevator push-rod
Flap lever
Flap lever detent box
Release button
Throttle lever
Brake lever
Elevator trimtab lever
Carburetor hot air lever
Bearing assembly
Pilot's handgrip
NOSE-GEAR
Steering stop
Nose-leg down tube
Rubber bungee (elasticated cord) shock absorber
Damper unit
Hoop
Pivoted fork
Axle bolt
Nose-wheel
STARBOARD WING
Wing strut
Starboard underwing fairing
Starboard top-wing fairing

Gliders, hang-gliders, and ultralights

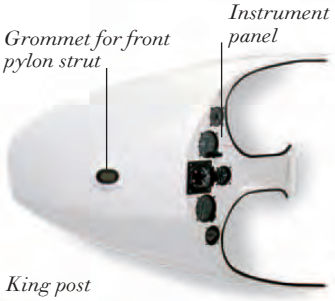
HANG-GLIDER

MODERN GLIDERS ARE AMONG the most graceful and aerodynamically efficient of all aircraft. Unpowered but with a large wingspan (up to about 82 ft, or 25 m), gliders use currents of hot, rising air (thermals) to stay aloft, and a rudder, elevators, and ailerons for control. Modern gliders have achieved flights of more than 900 miles (1,450 km) and altitudes above 49,000 ft (15,000 m).

Hang-gliders consist of a simple frame across which rigid or flexible material is stretched to form the wings. The pilot is suspended below the wings in a harness or body bag and, gripping a triangular A-frame, steers by shifting weight from side to side. Like gliders, hang-gliders rely on thermals for lift.

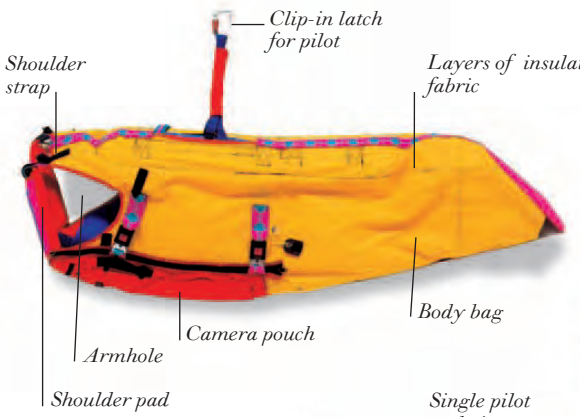
Ultralights are basically powered hang-gliders. A small engine and an open fiberglass car (trike), which can hold a crew of two, are suspended beneath a stronger version of a hang-glider frame; the frame may have rigid or flexible wings. Ultralight pilots, like hang-glider pilots, steer by shifting their weight against an A-frame. Ultralights can reach speeds of up to 100 mph (160 kph).

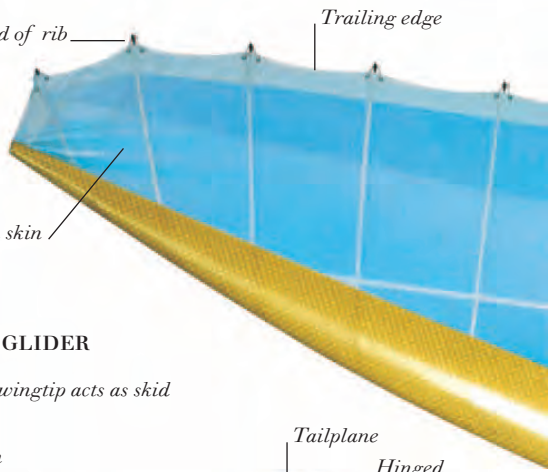
NOSE SHELL



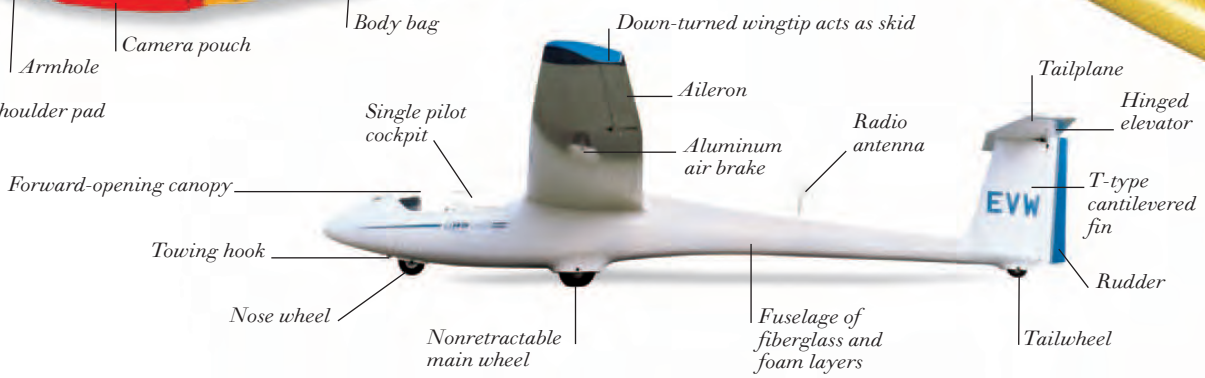
PEGASUS XL SE ULTRALIGHT

HANG-GLIDER BODY BAG

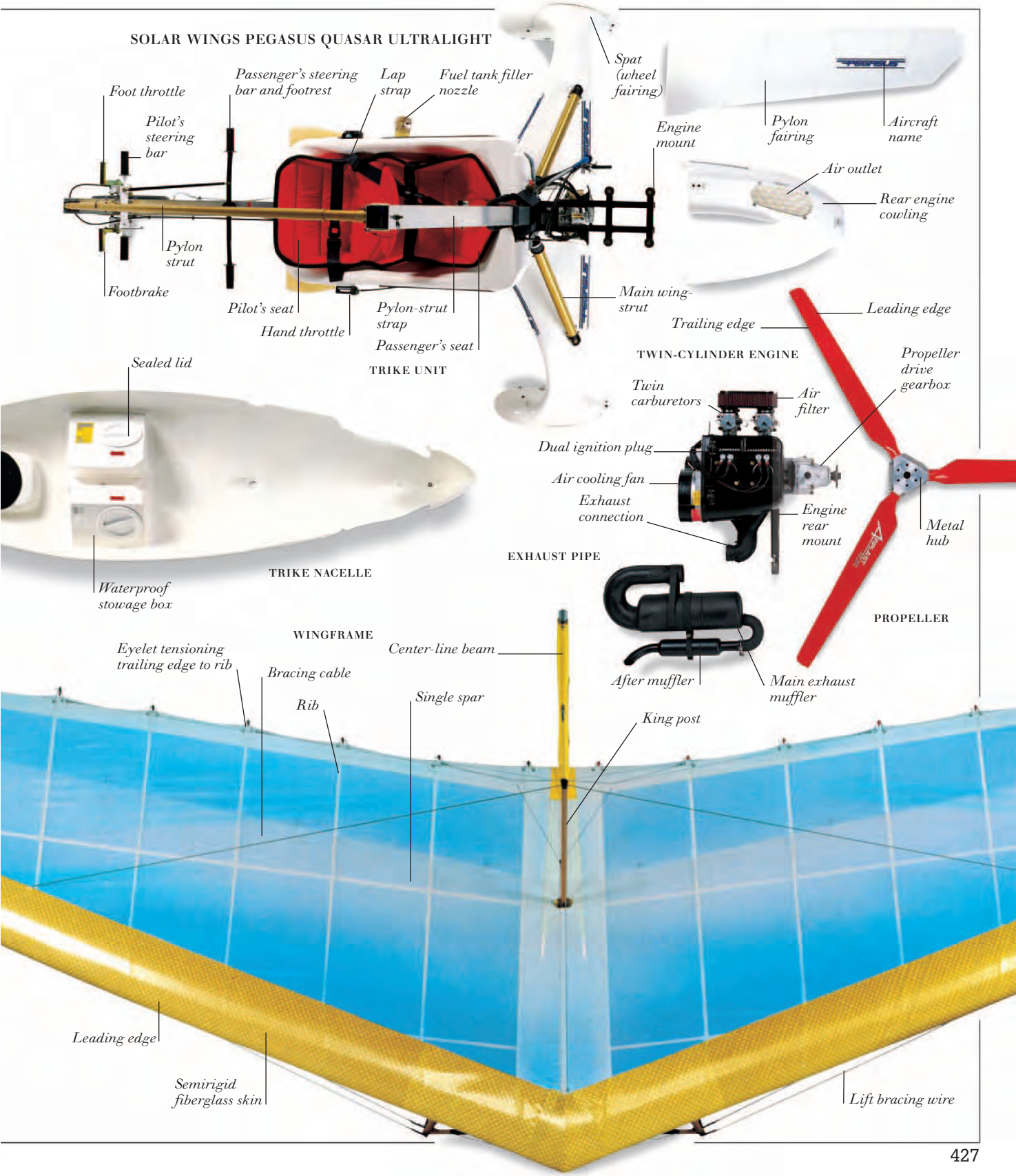




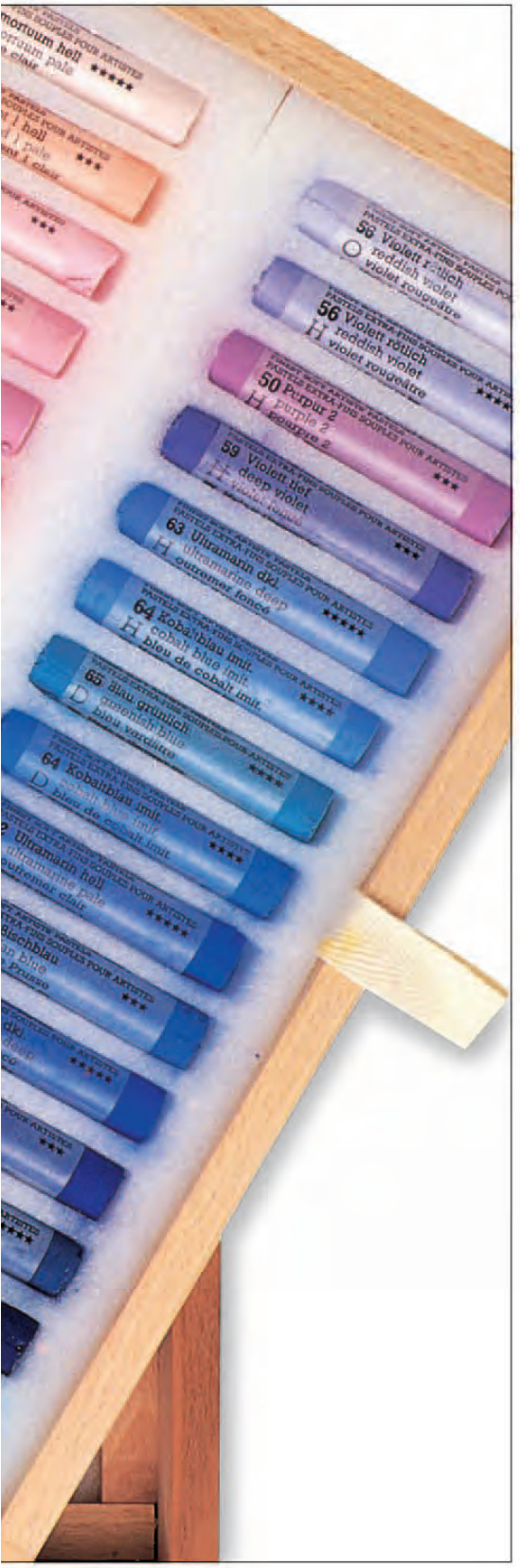
SCHLEICHER K23 GLIDER



SOLAR WINGS PEGASUS QUASAR ULTRALIGHT



03 Echtgelb 2 hell
sunproof yellow 2 light
jaune solide 2 clair
04 Echtgelb 3 dkl.
sunproof yellow 3 deep
jaune solide 3 foncé
05 Echtorange 1
sunproof orange 1
orange solide 1
42 Permanentrot 1 hell
permanent red 1 pale
rouge permanent 1 clair
44 Permanentrot 3 dkl.
permanent red 3 deep
rouge permanent 3 foncé
45 Krapplack
madder lake
laque de garance
46 Karminrot
carmine red
rouge carminé
49 Purpur 1
purple 1
pourpre 1
91 Graublau 1
grey blue 1
gris bleu 1
64 Kobaltblau lmit.
cobalt blue imit.
bleu de cobalt imit.
66 Preußischblau
Prussian blue
bleu de Prusse
57 Violett blaulich
bluish violet
violet bleuâtre
63 Ultramarin dkl.
ultramarine deep
outremer foncé
59 Violett tief
deep violet
violet foncé
68 Grün blaulich
bluish green
vert bleuâtre
75 Moosgrün 1
moss green 1
vert de mousse 1
85 Olivengrün 1
olive green 1
vert d'olive
71 Hellgrün
light green
vert clair
76 Moosgrün 2
moss green 2
vert de mousse 2
73 Laubgrün 2
leaf green 2
vert d'herbe 2
80 Kaltgrün 1
cold green 1
vert cru 1
30 Umbragrün
greenish umber
terre d'ombre verte
24 Caput mortuum dkl.
caput mortuum deep
tête morte foncé
23 Caput mortuum hell
caput mortuum pale
tête morte clair



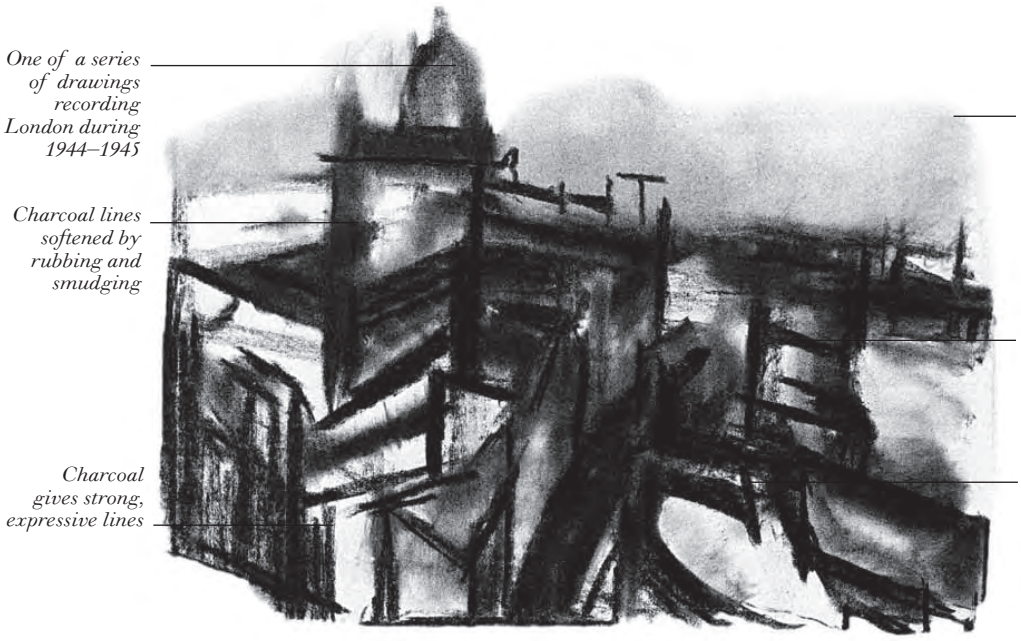
The Visual Arts

Drawing 430
Tempera 432
Fresco 434
Oils 436
Watercolor 438
Pastels 440
Acrylics 442
Calligraphy 444
Printmaking 1 446
Printmaking 2 448
Mosaic 450
Sculpture 1 452
Sculpture 2 454

Drawing

DRAWINGS CAN BE FINISHED WORKS OF ART, or preparatory studies for paintings and other visual arts. They can be made using a wide variety of drawing instruments such as pencils, graphite sticks, chalks, charcoal, pens and inks, and silver wires. The most common drawing instrument is the graphite pencil. A graphite pencil consists of a thin rod of graphite mixed with clay, encased in wood. Charcoal is one of the oldest drawing instruments. It is produced by firing twigs of willow, vine, or other woods at high temperatures in airtight containers. Erasers can be used to rub out marks made by drawing materials such as graphite pencils or charcoal, or to achieve a particular effect—such as smudging. Fixative is often applied—using a mouth diffuser or aerosol spray fixative—to prevent smudging once a drawing is finished. Silver lines can be produced by drawing silver wire across specially prepared paper—a technique known as silverpoint. The lines are permanent and cannot be erased. In time, the silver lines oxidize and turn brown.

EXAMPLE OF A SILVERPOINT DRAWING
The Adoration of the Magi, Leonardo da Vinci, 1481
Pen and ink over silverpoint on paper
6½ × 11½ in (16.5 × 29.2 cm)



EXAMPLE OF A CHARCOAL DRAWING
St. Paul's and the River, David Bomberg, 1945
Charcoal on paper
20 × 25⅛ in (50.8 × 65.8 cm)

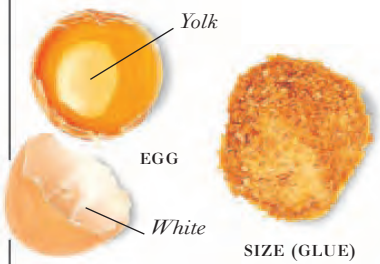
Tempera

ILLUMINATED MANUSCRIPT

THE TERM TEMPERA is applied to any paint in which pigment is tempered (mixed) with a water-based binding medium—usually egg yolk. Egg tempera is applied to a smooth surface such as vellum (for illuminated manuscripts) or more commonly to hardwood panels prepared with gesso—a mixture of chalk and size (glue). Hog hair brushes are used to apply the gesso. A layer of gesso grosso (coarse gesso) is followed by successive layers of gesso sotile (fine gesso) that are sanded between coats to provide a smooth, yet absorbent ground. The paint is applied with fine sable brushes in thin layers, using light brushstrokes. Tempera dries quickly to form a tough skin with a satin sheen. The luminous white surface of the gesso combined with the overlaid paint produces the brilliant crispness and rich colors particular to this medium. Egg tempera paintings are frequently gilded with gold. Leaves of finely beaten gold are applied to a bole (reddish-brown clay) base and polished by burnishing.

MATERIALS FOR GILDING

MATERIALS FOR TEMPERA PANEL PAINTING



GESSO

EGG YOLK BINDING MEDIUM

MORTAR AND PESTLE

EXAMPLES OF BRUSHES

EXAMPLE OF A TEMPERA PAINTING

Presentation in the Temple, Ambrogio Lorenzetti, 1342
Tempera on wood, 8 ft 5⅛ in × 5 ft 6 ⅛in (257 × 168 cm)

Altarpiece commissioned for Siena Cathedral, Italy

Textured gold ornament made by punching motifs into the gilded surface

The red tinge of the bole is just visible beneath the gold

Edge of a sheet of gold leaf

Crisp edge characteristic of tempera painting

Vine black used to create the dim cathedral interior

Highlights on the beard made by applying thin layers of white over dried paint

Red drapery painted in vermilion

Raised right hand and pointing finger is the gesture of prophecy

Receding floor tiles create the impression of depth

Patch of discolored varnish, left from last cleaning

PIGMENTS FOR FLESH-COLOR PAINTING

VERDACCIO

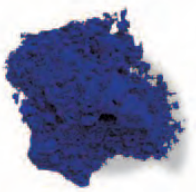
VERMILION AND LEAD WHITE

VERMILION

RED EARTH (IRON OXIDE)

EXAMPLES OF PIGMENTS

MALACHITE



ULTRAMARINE LAPIS LAZULI

VINE BLACK

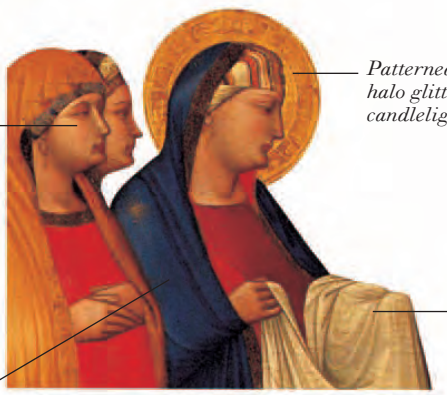
LEAD TIN YELLOW

Warm flesh tones achieved by layering vermilion and white over an undercoat of verdaccio

Patterned gold halo glitters in candlelight

Ultramarine lapis lazuli, as costly as gold, was reserved for significant figures such as the Virgin Mary

Craquelure (pattern of cracks in the paint)

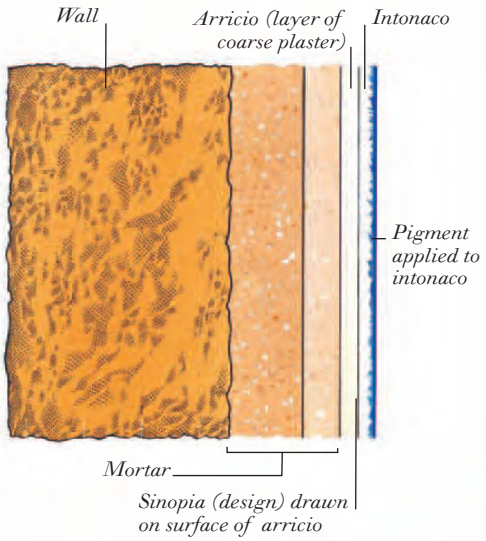


DETAIL FROM "PRESENTATION IN THE TEMPLE"

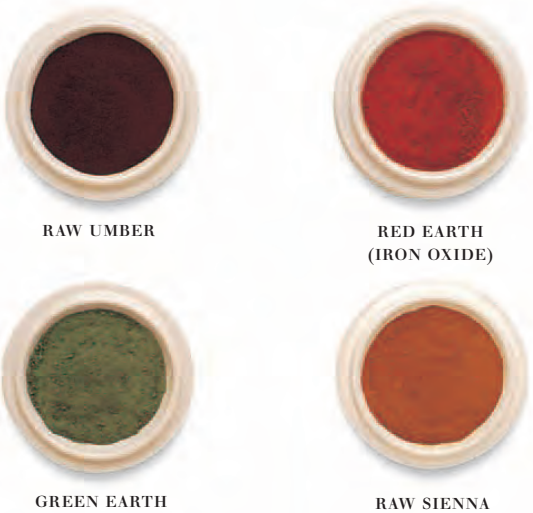
Fresco

FRESCO IS A METHOD OF WALL PAINTING. In buon fresco (true fresco), pigments are mixed with water and applied to an intonaco (layer of fresh, damp lime-plaster). The intonaco absorbs and binds the pigments as it dries making the picture a permanent part of the wall surface. The intonaco is applied in sections called giornate (daily sections). The size of each giornata depends on the artist's estimate of how much can be painted before the plaster sets. The junctions between giornate are sometimes visible on a finished fresco. The range of colors used in buon fresco are limited to lime-resistant pigments such as earth colors (below). Slaked lime (burnt lime mixed with water), bianco di San Giovanni (slaked lime that has been partly exposed to air), and chalk can be used to produce fresco whites. In fresco secco (dry fresco), pigments are mixed with a binding medium and applied to dry plaster. The pigments are not completely absorbed into the plaster and may flake off over time.

CROSS-SECTION SHOWING FRESCO LAYERS



EXAMPLES OF EARTH COLOR PIGMENTS



EXAMPLES OF FRESCO BRUSHES

INGREDIENTS FOR FRESCO WHITES

EXAMPLE OF A FRESCO

The Expulsion of the Merchants from the Temple, Giotto, c.1306
Fresco, 78 × 72 in (200 × 185 cm)

Temple acts as a backdrop for the action

Bianco di San Giovanni often used for fresco whites

Gold leaf applied to apostle's halo

Green earth pigment applied to robe

Child painted on top of apostle's robe

One of a series of frescoes in the Arena Chapel, Padua, Italy

Patches of azurite blue have turned green due to reaction with carbon dioxide

Hairline junction between giornate is visible

Red earth pigment applied in buon fresco has retained rich hue

Azurite blue applied in fresco secco has flaked off to reveal the plaster beneath

Dry, matte surface characteristic of buon fresco

Paint applied in buon fresco to child's face

White dove represents the Holy Ghost

Paint applied in fresco secco to child's body has flaked off

DETAIL FROM "THE EXPULSION"

Artist has to finish giornata before plaster dries

Junction between giornate

A fresco was generally worked in zones from the top down

Sinopia (design) sketched in red earth

Area with little detail can be painted quickly, allowing a larger giornata to be completed

Highly detailed area takes a longer time to paint, restricting the size of the giornata

GIORNATE (DAILY SECTIONS) IN "THE EXPULSION"

Oils

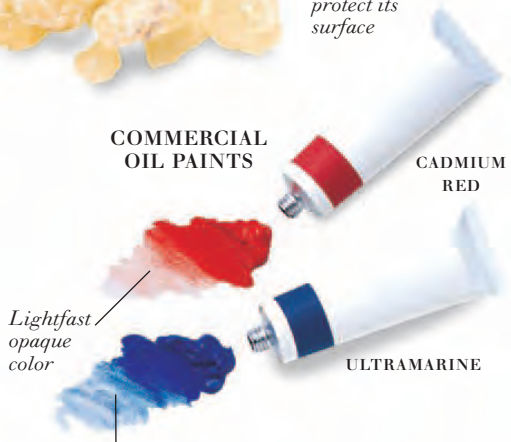
KIDNEY-SHAPED PALETTE

OIL PAINTS ARE MADE BY MIXING and grinding pigment with a drying vegetable oil such as linseed oil. The paint can be applied to many different surfaces and textures—the most common being canvas. Before painting, the canvas is stretched on a wooden frame and its surface is prepared with layers of size (glue) and primer. The two main types of brushes used in oil painting are stiff hog hair bristle brushes—generally used for covering large areas; and soft hair brushes made from sable or synthetic material—generally used for fine detail. Other tools, including painting knives, can also be used to achieve different effects. Oil paint can be applied thickly (a technique known as impasto), or can be thinned down using a solvent—such as turpentine. Varnishes are sometimes applied to finished paintings to protect their surface and to give them a matte or gloss finish.

DAMMAR RESIN VARNISH

Crystals are dissolved and applied to painting to protect its surface

COMMERCIAL OIL PAINTS



CADMIUM RED

Lightfast opaque color

ULTRAMARINE

Transparent color

LINSEED OIL

Oil derived from seeds of flax plant

EXAMPLES OF PIGMENTS

CADMIUM RED

CERULEAN BLUE

DOUBLE DIPPER (PALETTE ATTACHMENT)

Screw-top lid

Container for storing solvent or drying oil

HOG HAIR BRISTLE BRUSHES

Flat hog hair brush

Filbert hog hair brush

Flat hog hair brush

Filbert hog hair brush

Long, wooden handle

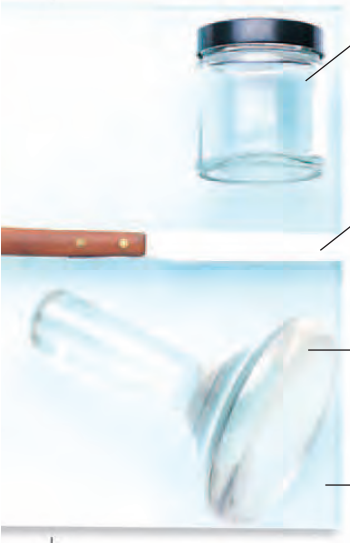
Protective, plastic case

SYNTHETIC BRUSH

Round hog hair brush

EXAMPLES OF BRUSHES

EQUIPMENT FOR MAKING OIL PAINT



Airtight jar for storing paint

Palette knife for mixing drying oil and pigment

Glass muller for grinding drying oil and pigment

Glass slab with abrasive surface

PAINTING KNIVES

TROWEL-SHAPED PAINTING KNIFE

DIAMOND-SHAPED PAINTING KNIFE

Blade

Blade

Cranked, steel shank

Cranked, steel shank

SABLE BRUSH

EXAMPLE OF AN OIL PAINTING

Fritillarias, Vincent van Gogh, 1886 Oil on canvas, 29 × 24 in (73.5 × 60.5 cm)

Artist's signature scratched in wet paint with the end of the brush

Background enlivened by dabs of white and green

Each leaf painted in a single, rapid stroke

Orange and blue (complementary colors) placed together to give maximum contrast and enhance one another to appear brighter

Impasto (deep ridges of paint applied in thick strokes)

Strong directional brushstrokes on table draw attention to the vase

Features of vase highlighted by generous touches of yellow

RADIAL STUDIO EASEL

Top sliding-block adjusts to canvas height

Canvas support

Height adjustment key

Angle adjustment key

Tripod

CANVAS STRETCHED ON WOODEN FRAME (VIEWED FROM THE BACK)

Staple

Canvas prepared with glue (size) and primer

Wooden frame

Unprimed canvas

EXAMPLES OF CANVASES

COTTON DUCK

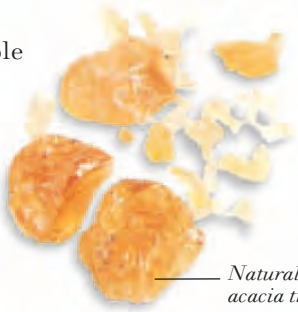
FINE LINEN

COARSE LINEN

Watercolor

WATERCOLOR PAINT IS MADE OF GROUND PIGMENT mixed with a watersoluble binding medium, usually gum arabic. It is usually applied to paper using soft hair brushes such as sable, goat hair, squirrel, and synthetic brushes. Watercolors are often diluted and applied as overlaying washes (thin, transparent layers) to build up depth of color. Washes can be laid in a variety of ways to create a range of different effects. For example, a wet-in-wet wash can be achieved by laying a wash on top of another wet wash. The two washes blend together to give a fused effect. Sponges are used to modify washes by soaking up paint so that areas of pigment are lightened or removed from the paper. Watercolors can also be applied undiluted—a technique known as dry brush—to create a broken-color effect. Watercolors are generally transparent and allow light to reflect from the surface of the paper through the layers of paint to give a luminous effect. They can be thickened and made opaque by adding body color (Chinese white).

GUM ARABIC



Natural sap from acacia tree

NATURAL SPONGE

ANATOMY OF A SABLE BRUSH

Soft red sable hair

Toe (tip)

Wooden handle

Hair trimmed and cemented into ferrule

Round ferrule

Hair tied with clove hitch knot

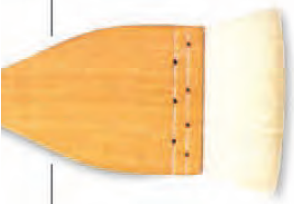
SOFT HAIR BRUSHES

ROUND SABLE BRUSH (NO. 6)

ROUND SABLE BRUSH (NO. 1)

SYNTHETIC WASH BRUSH

SQUIRREL MOP WASH BRUSH



LARGE GOAT HAKE WASH BRUSH

TUBES OF WATERCOLOR PAINT

WINSOR GREEN

CADMIUM YELLOW

PORTABLE BOX OF WATERCOLOR PAINTS

Painted color swatch

Chinese white

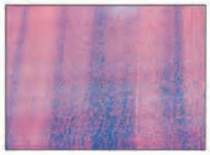
Pan of watercolor paint

Lid can be used for mixing colors

EXAMPLE OF A WATERCOLOR

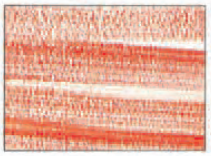
Burning of the Houses of Parliament, Turner, 1834
Watercolor on paper, 11½ × 17½ in (29.2 × 44.5 cm)

EXAMPLES OF WASHES

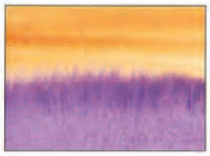


WASH OVER DRY BRUSH
Wash laid over paint applied with dry brush gives two-tone effect

GRADED WASH
Strong wash applied to tilted paper gives graded effect

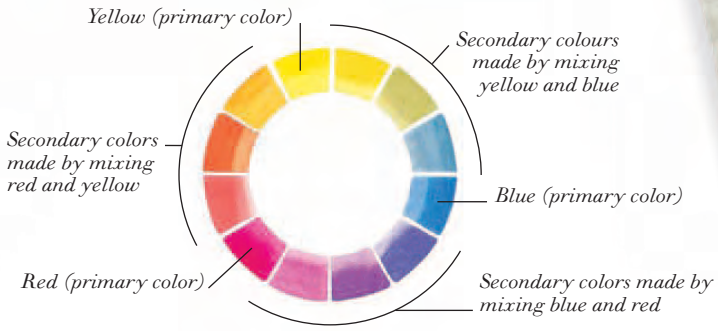


DRY BRUSH
Undiluted paint dragged across surface of paper gives broken effect



WET-IN-WET
Two diluted washes left to run together to give fused effect

COLOR WHEEL OF WATERCOLOR PAINTS

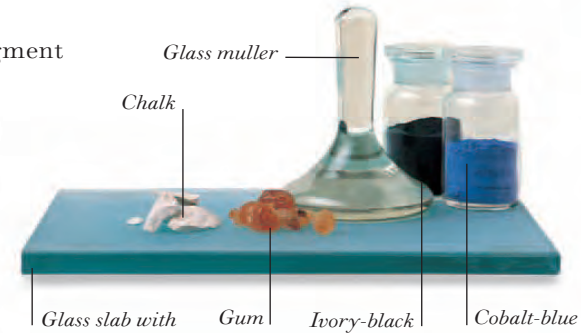


EXAMPLES OF WATERCOLOR PAPERS

Pastels

PASTELS ARE STICKS OF PIGMENT made by mixing ground pigment with chalk and a binding medium, such as gum arabic. They vary in hardness depending on the proportion of the binding medium to the chalk. Soft pastel—the most common form of pastel—contains just enough binding medium to hold the pigment in stick form. Pastels can be applied directly to any support (surface) with sufficient tooth (texture). When a pastel is drawn over a textured surface, the pigment crumbles and lodges in the fibers of the support. Pastel marks have a particular soft, matte quality and are suitable for techniques such as blending, scumbling, and feathering. Blending is a technique of rubbing and fusing two or more colors on the support using fingers or various tools such as tortillons (paper stumps), soft hair brushes, putty erasers, and soft bread. Scumbling is a technique of building up layers of pastel colors. The side or blunted tip of a soft pastel is lightly drawn over an underpainted area so that patches of the color beneath show through. Feathering is a technique of applying parallel strokes of color with the point of a pastel, usually over an existing layer of pastel color. A thin spray of fixative can be applied—using a mouth diffuser (see pp. 430-431) or aerosol spray fixative—to a finished pastel painting, or in between layers of color, to prevent smudging.

EQUIPMENT FOR MAKING PASTELS



EXAMPLES OF SOFT PASTELS

BOXED PASTEL SET

EQUIPMENT USED WITH PASTELS

PUTTY ERASER

BREAD

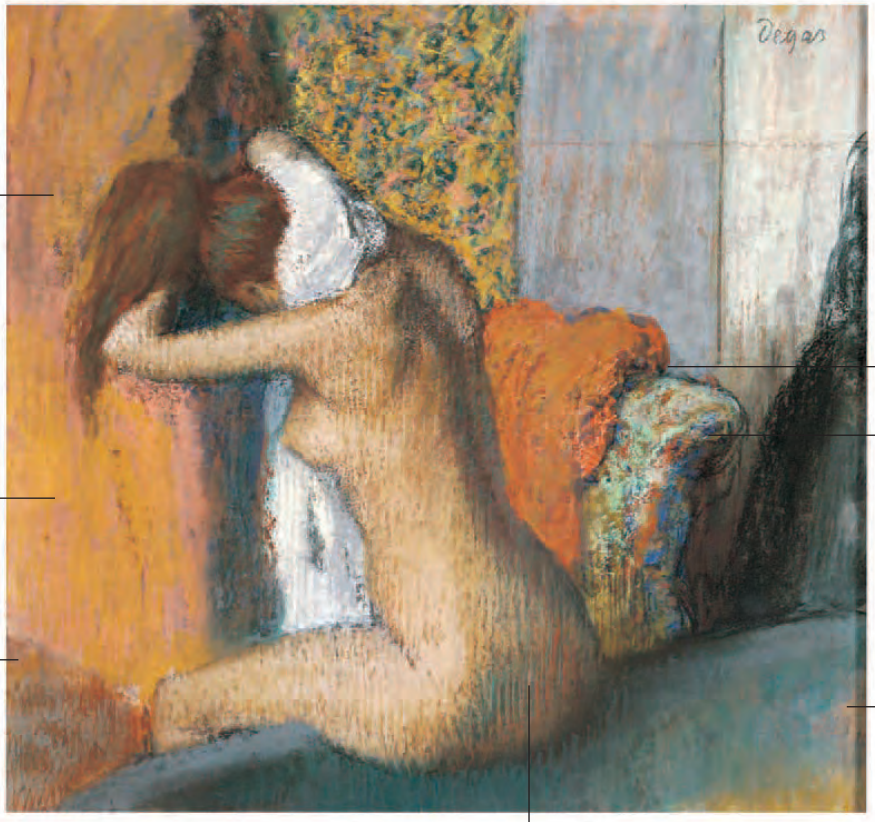
AEROSOL SPRAY FIXATIVE

SOFT HAIR BRUSH

TORTILLONS (PAPER STUMPS)

EXAMPLE OF A PASTEL PAINTING

Woman Drying her Neck, Edgar Degas, c.1898
Pastel on cardboard, 24½ x 25½ in (62.5 x 65.5 cm)



Pastels applied directly to support

Colors are blended together using fingers or tools such as tortillons

Built up layers of pastel

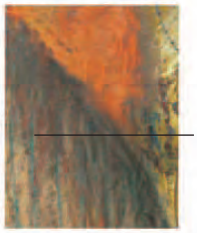
Rich color of fabric created by overlaying yellows and oranges

Broken colors, characteristic of scumbling technique

Toned color of paper visible beneath thinly applied pastels

Pure bright colors laid side by side produce strong contrasts

DETAIL FROM "WOMAN DRYING HER NECK"



Feathering technique used to produce skin tones

EXAMPLES OF TEXTURED PAPERS AND PASTEL BOARDS

WATERCOLOR PAPER (ROUGH TEXTURE)

GLASS PAPER

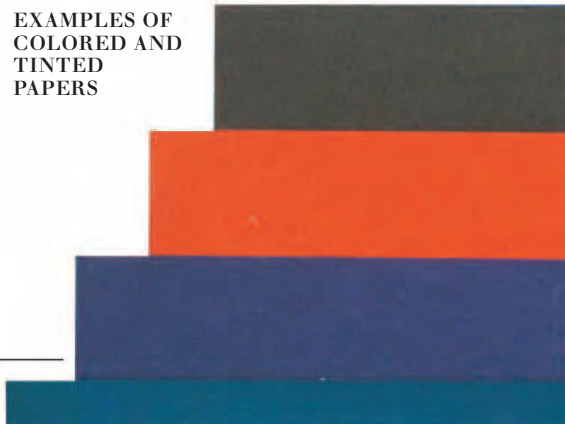
WATERCOLOR PAPER (MEDIUM TEXTURE)

INGRES PAPER

FLOCKED PASTEL BOARD

CANSON PAPER

EXAMPLES OF COLORED AND TINTED PAPERS

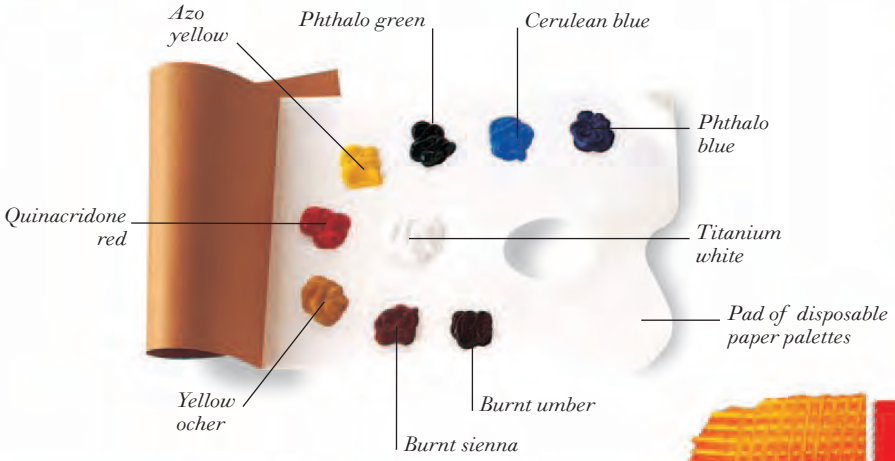


Acrylics

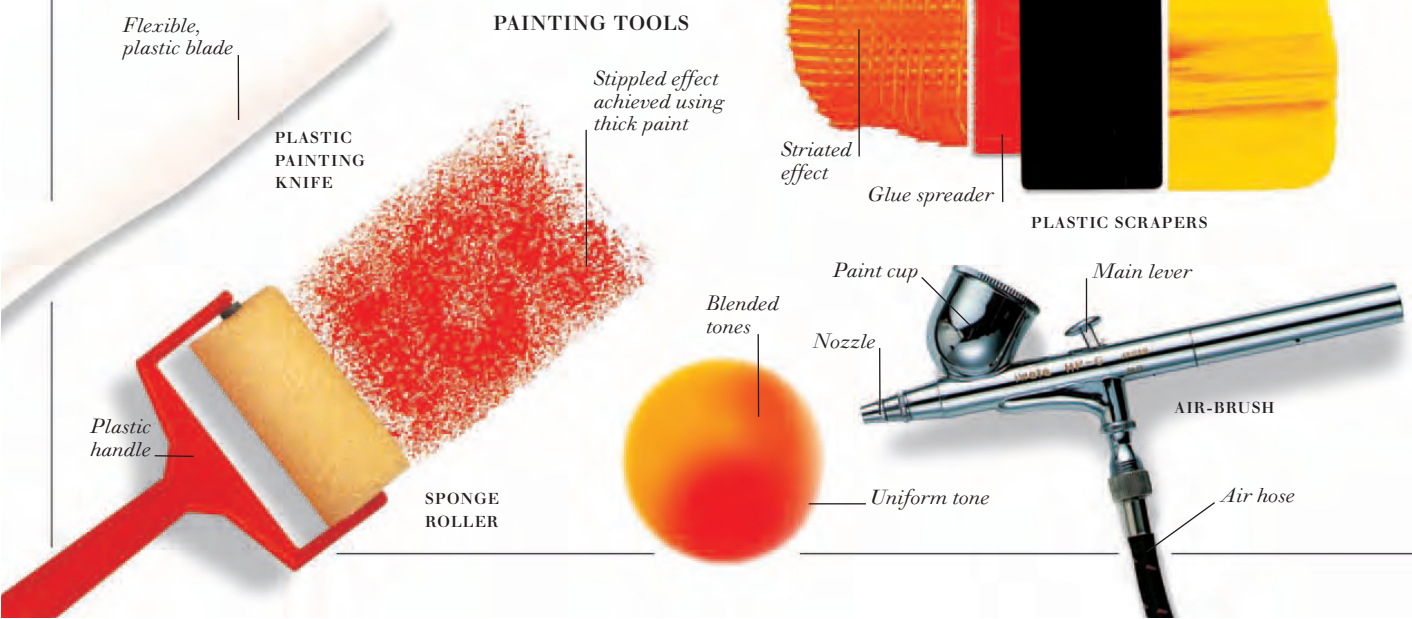
ACRYLIC PAINT IS MADE BY MIXING PIGMENT with a synthetic resin. It can be thinned with water but dries to become water insoluble. Acrylics are applied to many surfaces, such as paper and acrylic-primed board and canvas. A variety of brushes, painting knives, rollers, air-brushes, plastic scrapers, and other tools are used in acrylic painting. The versatility of acrylics makes them suitable for a wide range of techniques. They can be used opaquely or—by adding water—in a transparent, watercolor style. Acrylic mediums can be added to the paint to adjust its consistency for special effects such as glazing and impasto (ridges of paint applied in thick strokes) or to make it more matt or glossy. Acrylics are quick-drying, which allows layers of paint to be applied on top of each other almost immediately.

EXAMPLES OF BRUSHES

EXAMPLES OF PAINTS USED IN ACRYLICS



PAINTING TOOLS



EXAMPLE OF AN ACRYLIC PAINTING

A Bigger Splash, David Hockney, 1967
Acrylic on canvas, 95½ x 96 in (242.5 x 243.8 cm)

Paint applied evenly using a roller

Cotton duck canvas support (surface)

Flatness of rollered areas enhanced by adding gel medium to the paint

Masking tape stuck on to canvas to define main shapes, and paint applied within these areas using a roller

Thin strip of pool edge left unpainted

Splash painted using thicker paint and small brush

Imprecise edge on end of spring board where paint has seeped under masking tape

EXAMPLES OF ACRYLIC PAINTS AND TECHNIQUES

Opaque effect

Extruded (squeezed) effect

Paint applied using painting knife

PURPLE ACRYLIC PAINT

YELLOW ACRYLIC PAINT

ORANGE ACRYLIC PAINT

Transparent, watercolor effect

Translucent, impasto glaze

Thick impasto with coarse texture

BLUE ACRYLIC PAINT DILUTED WITH WATER

GREEN ACRYLIC PAINT MIXED WITH GEL MEDIUM

RED ACRYLIC PAINT MIXED WITH TEXTURE PASTE

Calligraphy

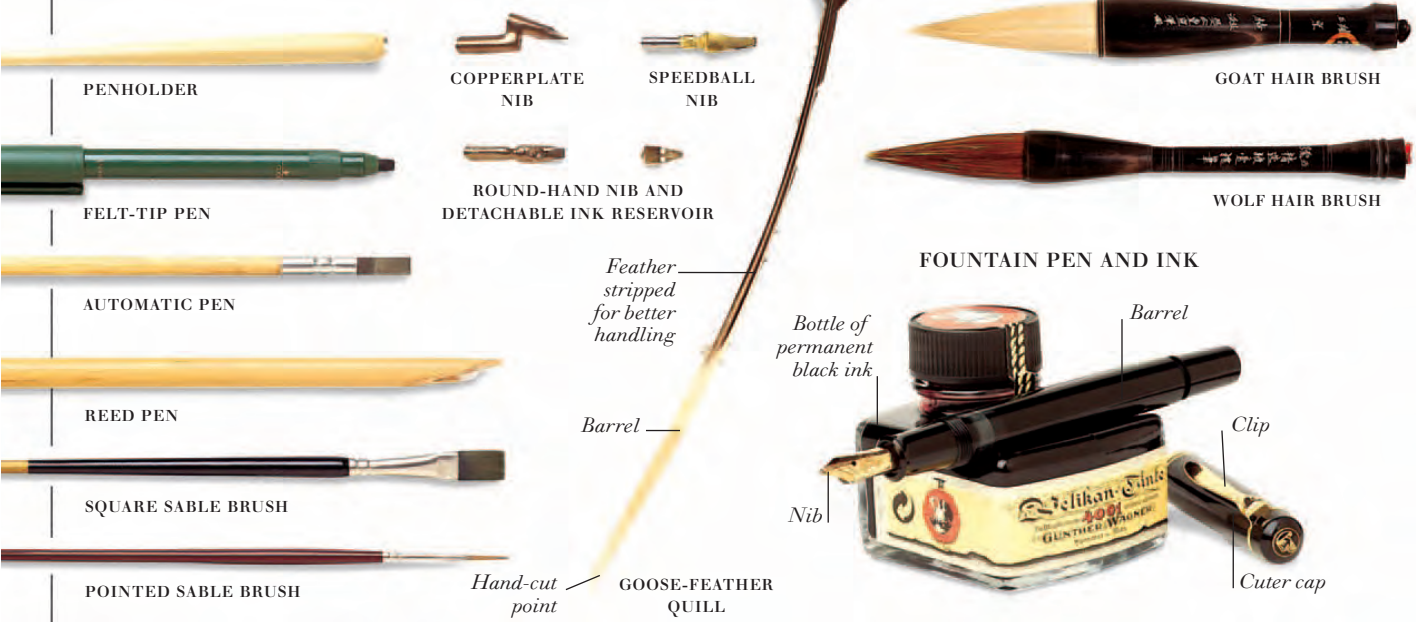
CALLIGRAPHY IS BEAUTIFULLY FORMED LETTERING. The term applies to written text and illumination (the decoration of manuscripts using gold leaf and color). The essential materials needed to practice calligraphy are a writing tool, ink, and a writing surface. Quills are among the oldest writing tools. They are usually made from goose or turkey feathers, and are noted for their flexibility and ability to produce fine lines. A quill point, however, is not very durable and constant recutting and trimming is required. The most commonly used writing instrument in Western calligraphy is a detachable, metal nib held in a penholder. The metal nib is very durable, and there are a wide range of different types. Particular types of nibs—such as copperplate, speedball, and round-hand nibs—are used for specific styles of lettering. Some nibs have integral ink reservoirs and others have reservoirs that are detachable. Brushes are also used for writing, and for filling in outlined letters and painting decoration. Other writing tools used in calligraphy are fountain pens, felt-tip pens, rotring pens, and reed pens. Calligraphy inks may come in liquid form, or as a solid ink stick. Ink sticks are ground down in distilled water to form a liquid ink. The most common writing surfaces for calligraphy are good quality, smooth -surfaced papers. To achieve the best writing position, the calligrapher places the paper on a drawing board set at an angle.

EQUIPMENT USED IN BRUSH LETTERING

BRUSHES AND BRUSH REST

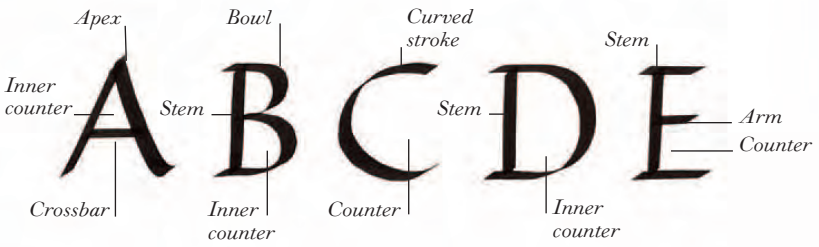
INK STICK AND STONE

PENS, NIBS, AND BRUSHES USED IN CALLIGRAPHY

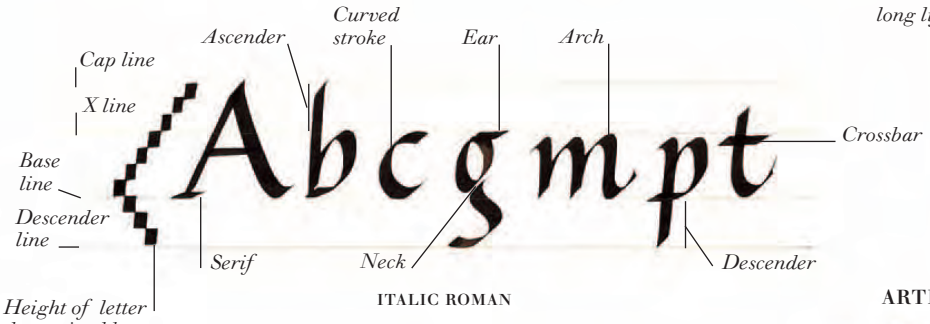


FOUNTAIN PEN AND INK

EXAMPLES OF LETTERING STYLES



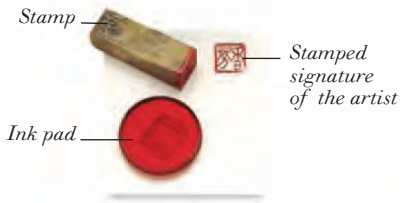
ROMAN CAPITALS

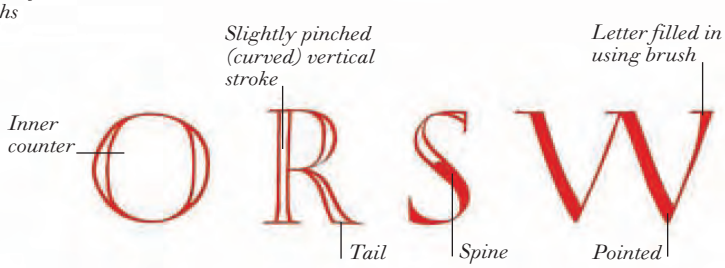


ITALIC ROMAN

CHINESE LETTERING

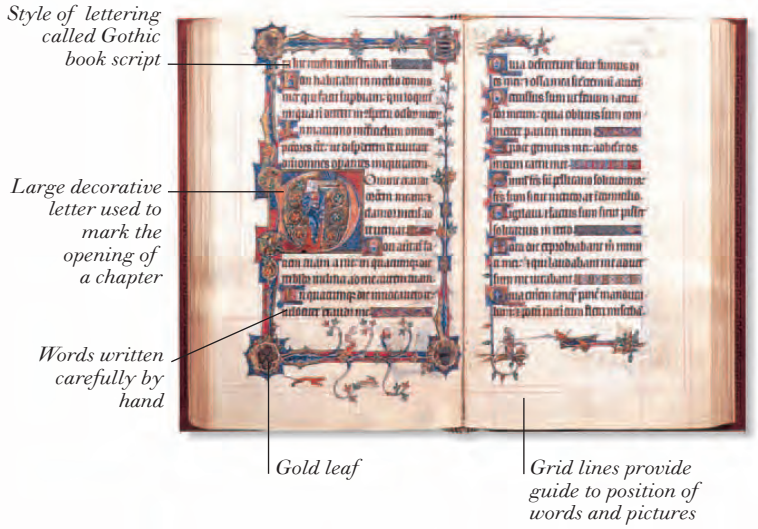
ARTIST'S STAMP



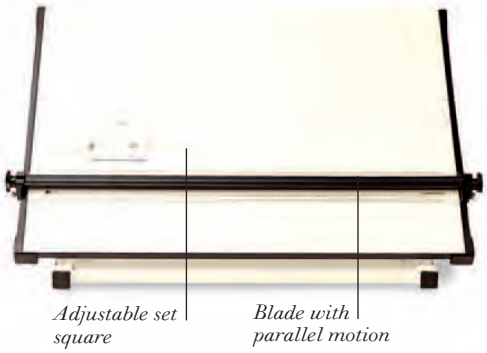


VERSAL

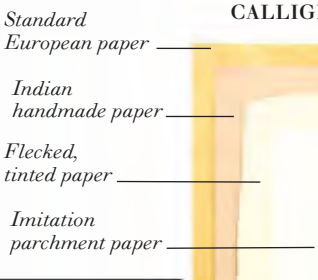
AN ILLUMINATED MANUSCRIPT



DRAWING BOARD



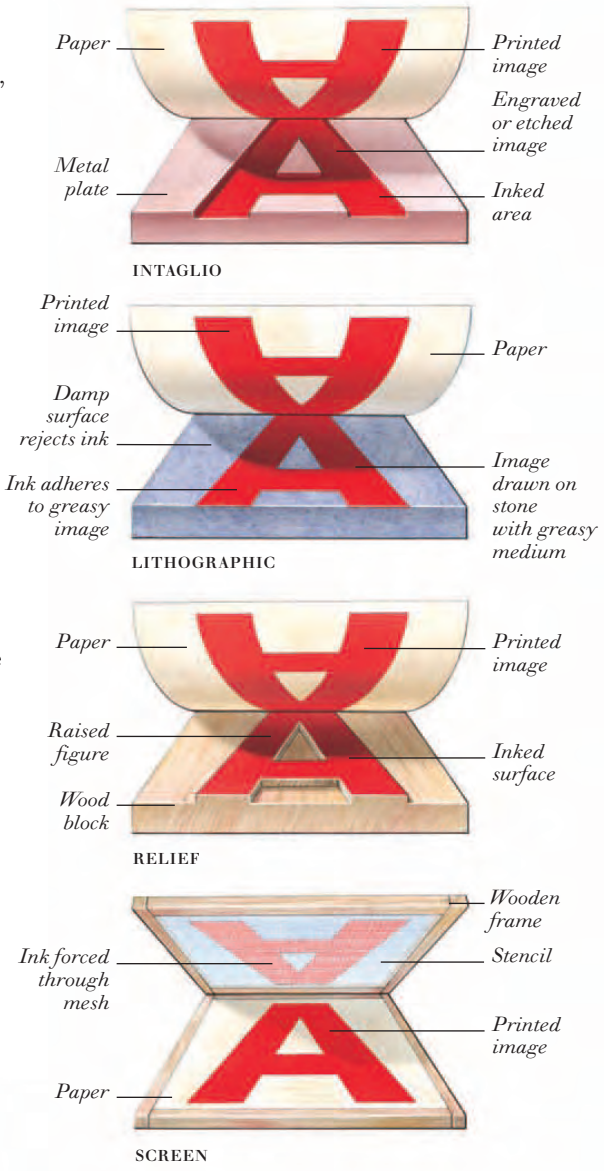
EXAMPLES OF CALLIGRAPHY PAPERS

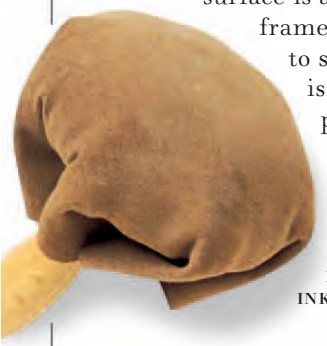


Printmaking 1

PRINTS ARE MADE BY FOUR BASIC printing processes—intaglio, lithographic, relief, and screen. In intaglio printing, lines are engraved or etched into the surface of a metal plate. Lines are engraved by hand using sharp metal tools. They are etched by corroding the metal plate with acid, using acid-resistant ground to protect the areas not to be etched. The plate is then inked and wiped, leaving the grooves filled with ink and the surface clean. Dampened paper is laid over the plate, and both paper and plate are passed through the rollers of an etching press. The pressure of the rollers forces the paper into the grooves, so that it takes up the ink, leaving an impression on the paper. Lithographic printing is based on the antipathy between grease and water. An image is drawn on a surface—usually a stone or metal plate—with a greasy medium, such as tusche (lihographic ink). The greasy drawing is fixed on to the plate by applying an acidic solution, such as gum arabic. The surface is then dampened and rolled with ink. The ink adheres only to the greasy areas and is repelled by the water. Paper is laid on the plate and pressure is applied by means of a press. In relief printing, the nonprinting areas of a wood or linoleum block are cut away using gouges, knives, and other tools. The printing areas are left raised in relief and are rolled with ink. Paper is laid on the inked block and pressure is applied by means of a press or by burnishing (rubbing) the back of the paper. The most common forms of relief printing are woodcut, wood engraving, and linocut. In screen printing, the printing surface is a mesh stretched across a wooden frame. A stencil is applied to the mesh to seal the nonprinting areas and ink is scraped through the mesh to produce an image.

THE FOUR MAIN PRINTING PROCESSES



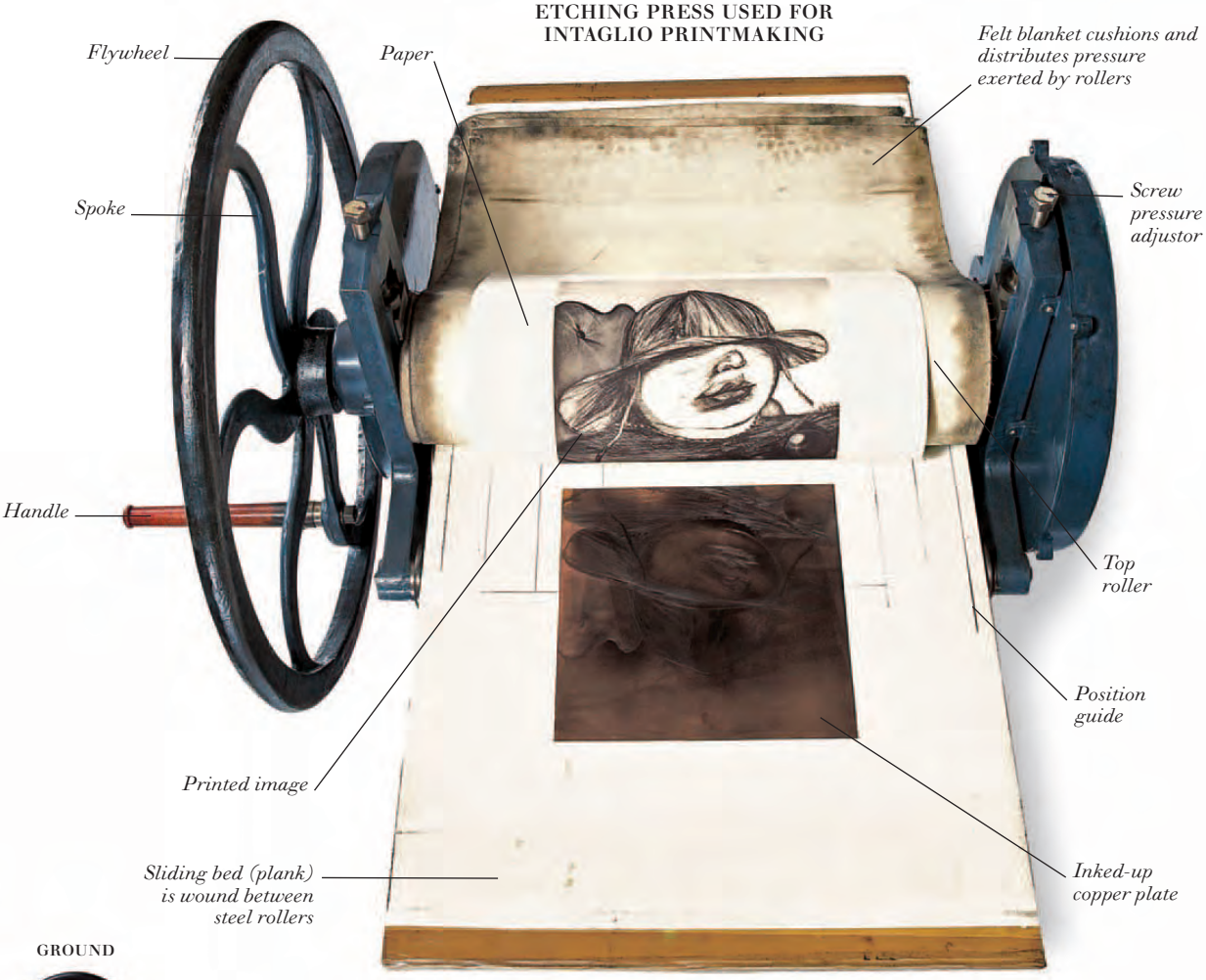


LEATHER INK DABBER

EQUIPMENT USED IN INTAGLIO PRINTING

ROCKER SCRIBER ROULETTE SCRAPER BURNISHER CLAMP

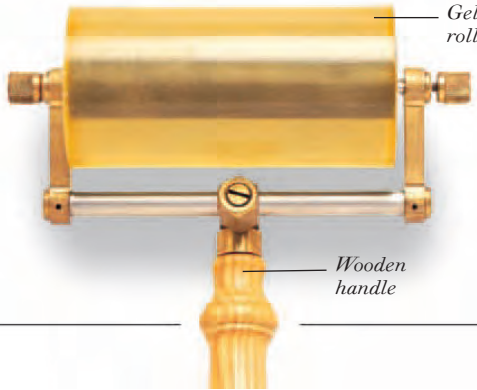
ETCHING PRESS USED FOR INTAGLIO PRINTMAKING



GROUND

Acid-resistant ground rolled onto metal plate before etching

GROUND ROLLER



EXAMPLE OF AN INTAGLIO PRINT
Annie with a Sun Hat, Jock McFadyen, 1993
Etched copper plate, 16 × 15¾ in (41 × 40 cm)

EXAMPLES OF PRINTING PAPERS

Printmaking 2

EXAMPLE OF A LITHOGRAPHIC STONE AND PRINT

Crown Gateway 2, Mandy Bonnell, 1987
Lithograph, 19½ × 15¾ in (50 × 40 cm)

IMAGE DRAWN ON STONE

LITHOGRAPHIC PRINT

EXAMPLE OF A SCREEN PRINT

Sea Change, Patrick Hughes, 1992
Screen print, 30 × 37 in (77 × 94.5 cm)

EQUIPMENT USED IN LITHOGRAPHIC PRINTING

CRAYON AND HOLDER

LITHOGRAPHIC PENCIL

TUSCHE (LITHOGRAPHIC INK) PEN

ERASING STICK

EXPANDABLE SPONGE

TUSCHE (LITHOGRAPHIC INK) STICK

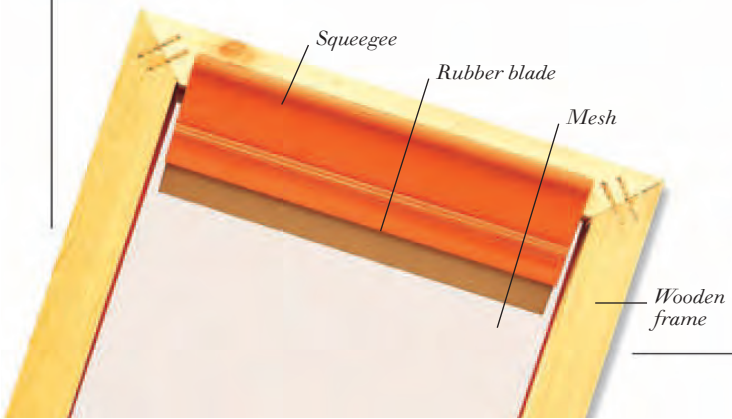
RUBBING INK

INK ROLLER

MILD ACIDIC SOLUTION

GUM ARABIC SOLUTION

SCREEN AND SQUEEGEE



WATER-BASED SCREEN PRINTING INKS

BLUE ACRYLIC INK

RED ACRYLIC INK

BROWN TEXTILE INK

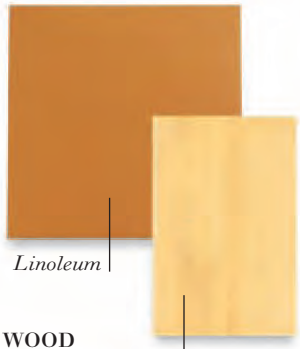
EQUIPMENT USED IN RELIEF PRINTING

V-SHAPED GOUGE

INK ROLLER

Rubber roller

LINOLEUM AND WOODCUT BLOCK



Linoleum

Side-grain wood block

U-SHAPED GOUGE

GRAVER

KNIFE

SCORPER

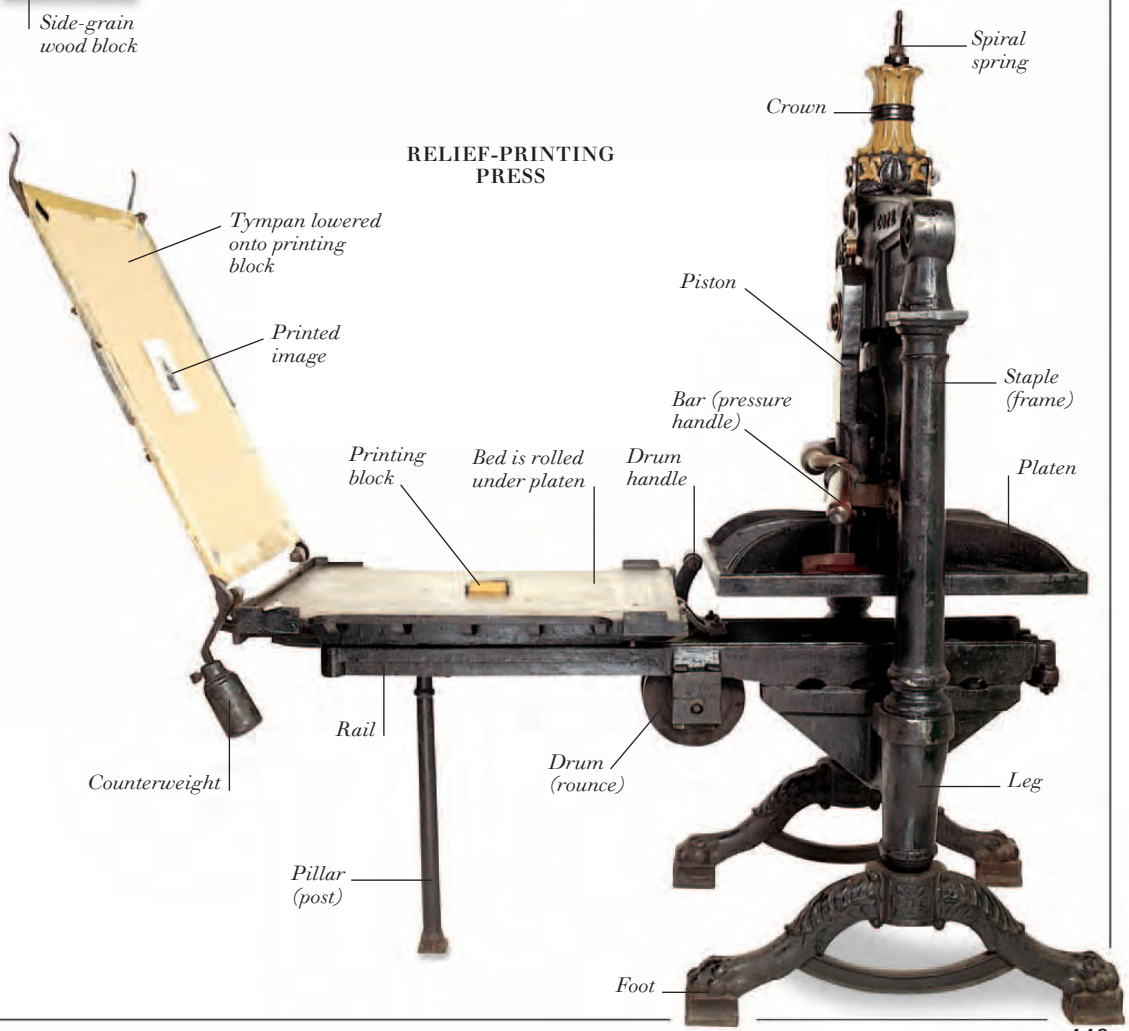
WOOD ENGRAVING

END-GRAIN WOOD BLOCK

INKED-UP ENGRAVED BLOCK

WOOD ENGRAVING PRINT

RELIEF-PRINTING PRESS



Mosaic

MOSAIC IS THE ART OF MAKING patterns and pictures from tesserae (small, colored pieces of glass, marble, and other materials). Different materials are cut into tesserae using different tools. Smalti (glass enamel) and marble are cut into pieces using a hammer and a hardy (a pointed blade) embedded in a log. Vitreous glass is cut into pieces using a pair of pliers. Mosaics can be made using a direct or indirect method. In the direct method, the tesserae are laid directly into a bed of cement-based adhesive. In the indirect method, the design is drawn in reverse on paper or cloth. The tesserae are then stuck face-down on the paper or cloth using water-soluble glue. Adhesive is spread with a trowel on to a solid surface—such as a wall—and the back of the mosaic is laid into the adhesive. Finally, the paper or cloth is soaked off to reveal the mosaic. Gaps between tesserae can be filled with grout. Grout is forced into gaps by dragging a grouting squeegee across the face of the mosaic. Mosaics are usually used to decorate walls and floors, but they can also be applied to smaller objects.

EXAMPLE OF A MOSAIC (DIRECT METHOD)
Seascape, Tessa Hunkin, 1993
Smalti mosaic on board
31½ in (80 cm) diameter

SMALTI (GLASS ENAMEL)

RED SMALTI

YELLOW SMALTI

BLUE SMALTI

EQUIPMENT FOR BREAKING MARBLE

PLIERS

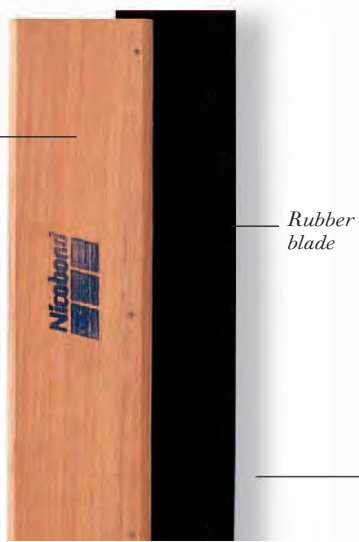
MOSAIC TOOLS

CEMENT-BASED ADHESIVE

GROUT

TROWEL

GROUTING SQUEEGEE



STAGES IN THE CREATION OF A MOSAIC (INDIRECT METHOD)

COLOR SKETCH
A color sketch is drawn in oil pastel to give a clear impression of how the finished mosaic will look.

REVERSE IMAGE
Tesserae are glued face-down on reverse image on paper. Mosaic is then attached to solid surface and paper is removed.

MOSAIC POT

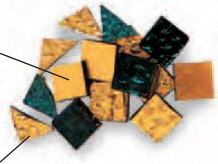
MOSAIC MOSQUE DESIGN

FINISHED MOSAIC
Goldfish, Tessa Hunkin, 1993
Vitreous glass mosaic on board
14 × 10 in (35.5 × 25.5 cm)

VITREOUS GLASS

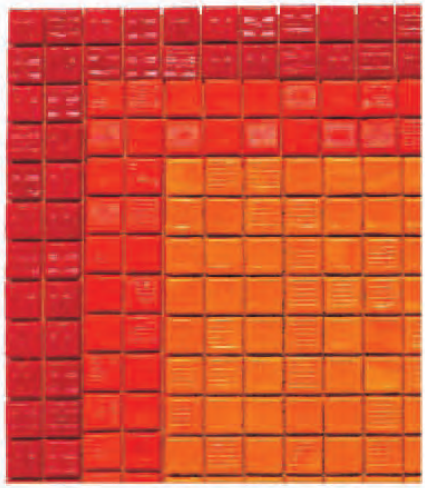
RED VITREOUS GLASS

GREEN VITREOUS GLASS WITH GOLD LEAF



BLUE VITREOUS GLASS

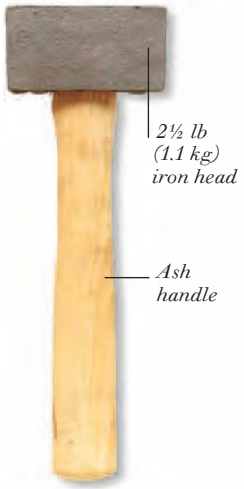
SHEETS OF VITREOUS GLASS



Sculpture 1

THE TWO TRADITIONAL METHODS OF MAKING SCULPTURE are carving and modeling. A carved sculpture is made by cutting away the surplus from a block of hard material such as stone, marble, or wood. The tools used for carving vary according to the material being carved. Heavy steel points, claws, and chisels that are struck with a lump hammer are generally used for stone and marble. Sharp gouges and chisels that are struck with a wooden mallet are used for wood. Sculptures formed from hard materials are generally finished by filing with rasps, rifflers, and other abrasive implements. Modeling is a process by which shapes are built up, using malleable materials such as clay, plaster, and wax. The material is cut with wire-ended tools and modeled with the fingers or a variety of hardwood and metal implements. For large or intricate modeled sculptures an armature (frame), made from metal or wood, is used to provide internal support. Sculptures formed in soft materials may harden naturally or can be made more durable by firing in a kiln. Modeled sculptures are often first designed in wax or another material to be cast later in a metal (see pp. 454-455) such as bronze. The development of many new materials in the 20th century has enabled sculptors to experiment with new techniques such as construction (joining preformed pieces of material such as machine components, mirrors, and furniture) and kinetic (mobile) sculpture.

EXAMPLES OF MARBLE CARVING TOOLS



LUMP HAMMER

WIDE MARBLE CLAW

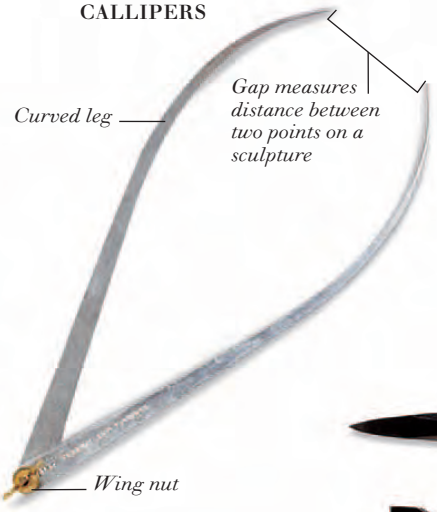
NARROW MARBLE CLAW

POINT

FLAT CHISEL

BULLNOSE CHISEL

CALLIPERS



EXAMPLES OF WOOD-CARVING TOOLS

CABINET RASP

STRAIGHT GOUGE

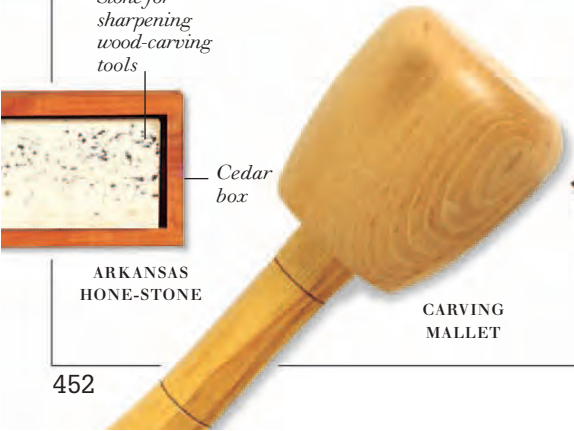
SALMON BEND GOUGE

CHISEL

Stone for sharpening wood-carving tools

Cedar box

ARKANSAS HONE-STONE



CARVING MALLET

EXAMPLES OF RIFFLERS (FOR STONE, MARBLE, AND WOOD)

12 IN (30 CM) RIFFLER

6 IN (15 CM) RIFFLER

Surface for sharpening stone-carving tools

DIAMOND WHETSTONE

EXAMPLE OF A CARVED WOOD SCULPTURE
Mary Magdalene, Donatello, 1454-1455
Poplar wood, height 6 ft 2 in (188 cm)

Delicately modeled hand carved with a chisel

Hair highlighted with gold leaf

Figure cut from single length of poplar

Deep ridges of hair cut with a gouge

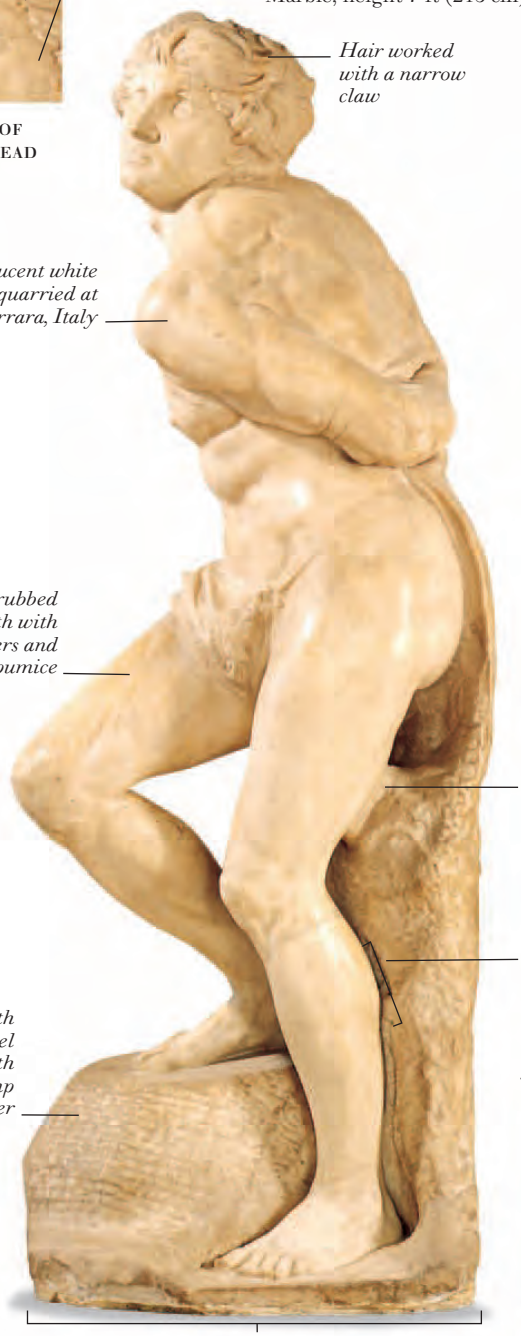
Wood prepared with gesso (chalk and glue) and painted

Tiny holes along the hairline made with a point

Soft skin texture tooled with a fine-toothed marble claw

DETAIL OF SLAVE'S HEAD

EXAMPLE OF A CARVED MARBLE SCULPTURE
The Rebel Slave, Michelangelo, 1513-1516
Marble, height 7 ft (213 cm)



Hair worked with a narrow claw

Translucent white marble, quarried at Carrara, Italy

Surface rubbed smooth with rifflers and pumice

Strut gives added support to long slender limb

Series of tiny punch holes, made with a fine point, outline the form

Base scored with jagged parallel cuts made with point and lump hammer

The dimensions of the marble block determine the size of the sculpture

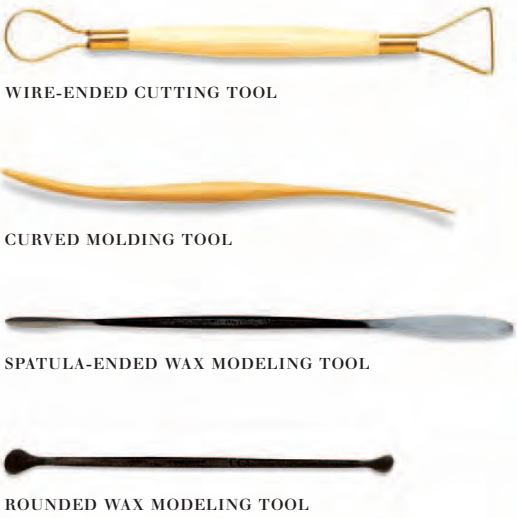
Foot carved in deep relief

Rough surface made by driving a point into the marble at an oblique angle

DETAIL OF SLAVE'S FOOT

Sculpture 2

EXAMPLES OF MODELING TOOLS



WIRE-ENDED CUTTING TOOL

CURVED MOLDING TOOL

SPATULA-ENDED WAX MODELING TOOL

ROUNDED WAX MODELING TOOL

EXAMPLES OF BRONZE FINISHING TOOLS

HOOKED RIFFLER

POINTED RIFFLER

SPIRIT LAMP (FOR HEATING WAX MODELING TOOLS)

STAGES IN THE LOST-WAX METHOD OF CASTING

Based on Mars, Giambologna, c.1546

ORIGINAL MODEL
An original, solid wax model is made and preserved so that numerous replicas can be cast.

HOLLOW WAX FIGURE IS CAST
A new, hollow wax model is cast from the original model. It is filled with a plaster core that is held in place with nails. Wax runners and risers are attached.

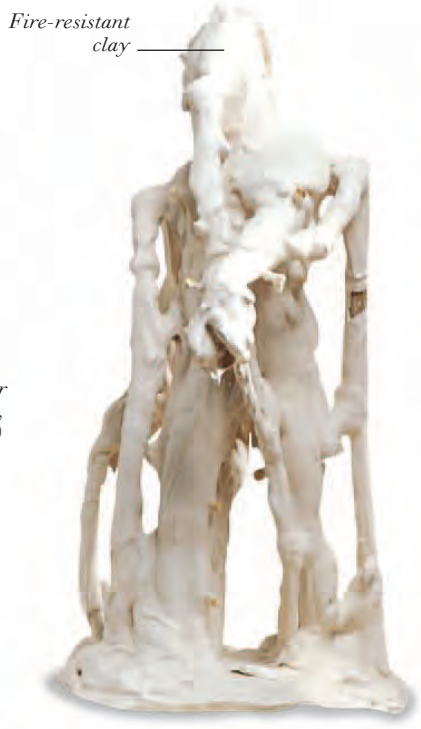
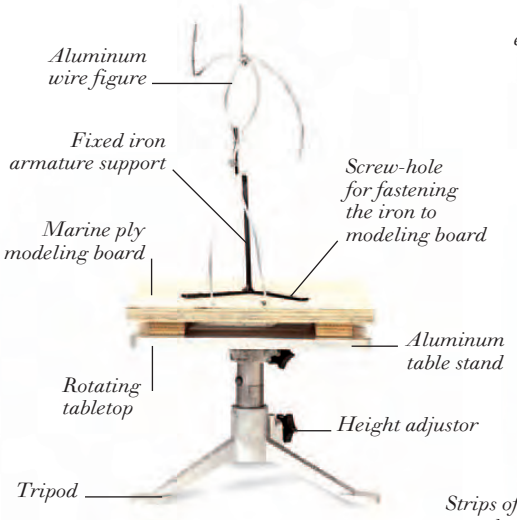


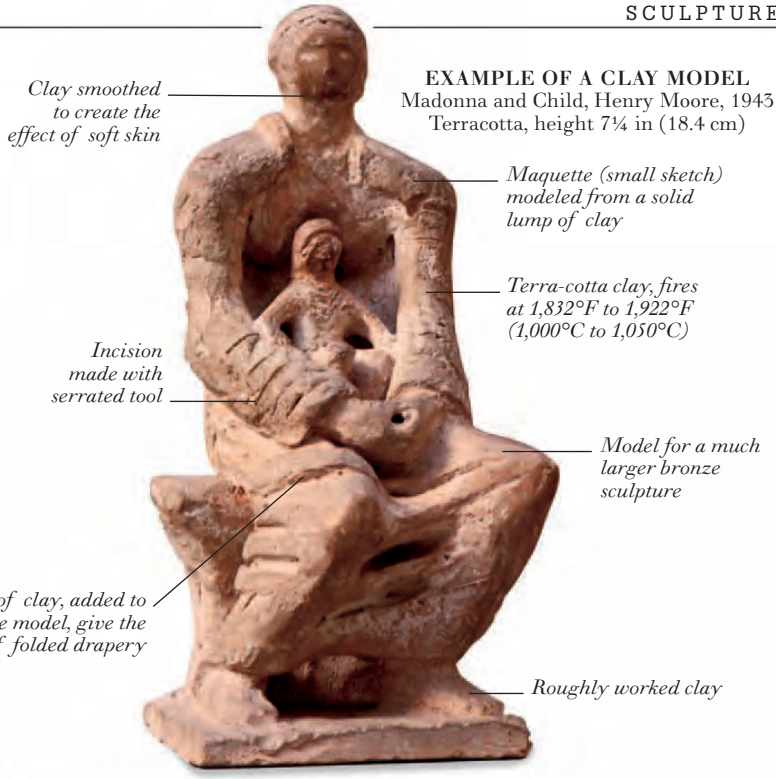
FIGURE IS BAKED IN CASTING MOLD
The model is encased in clay and baked. The wax melts away (through the channels made by the wax rods) and is replaced by molten bronze.

MODELING STAND AND ARMATURE



EXAMPLE OF A CLAY MODEL

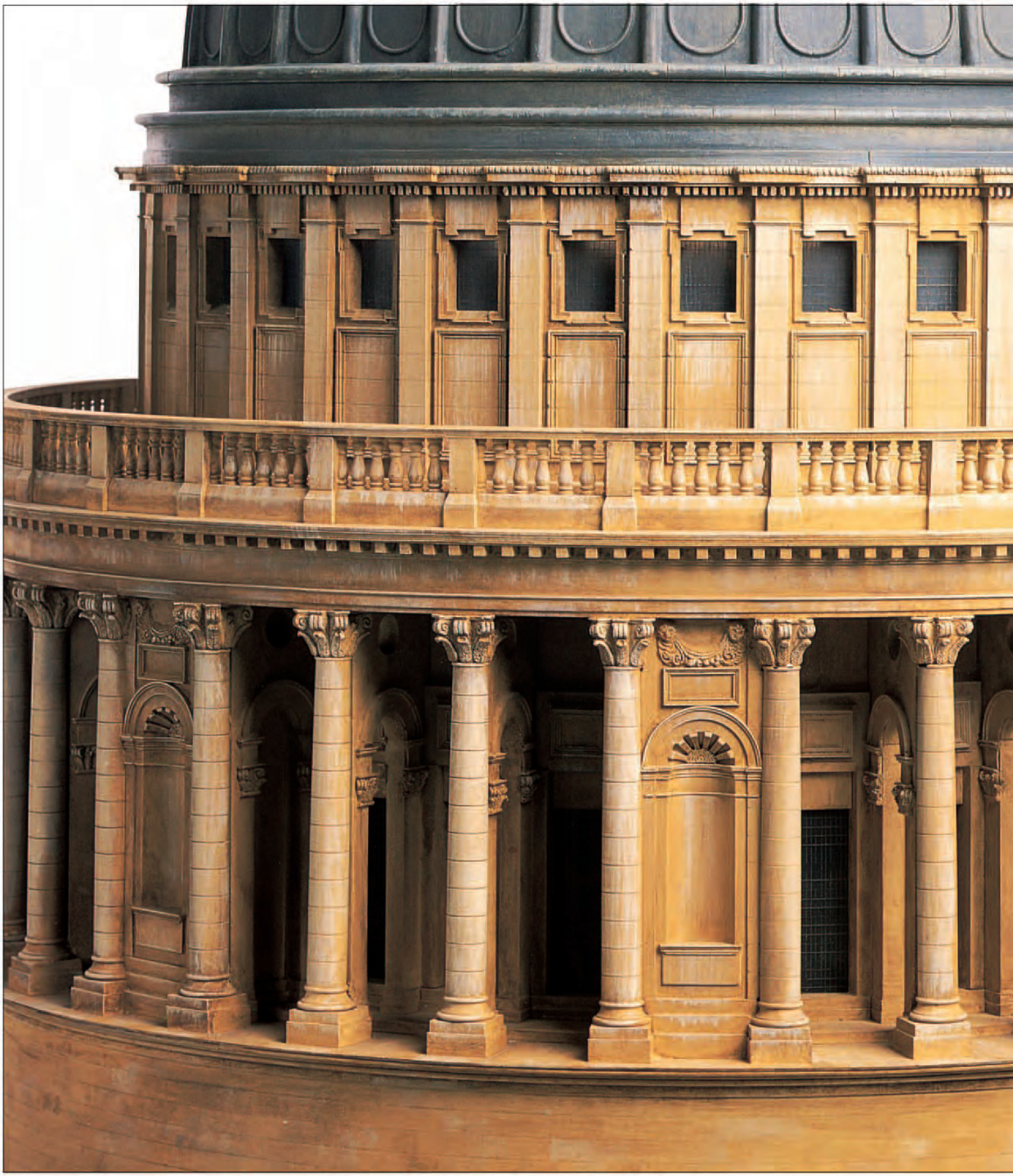
Madonna and Child, Henry Moore, 1943
Terracotta, height 7¼ in (18.4 cm)

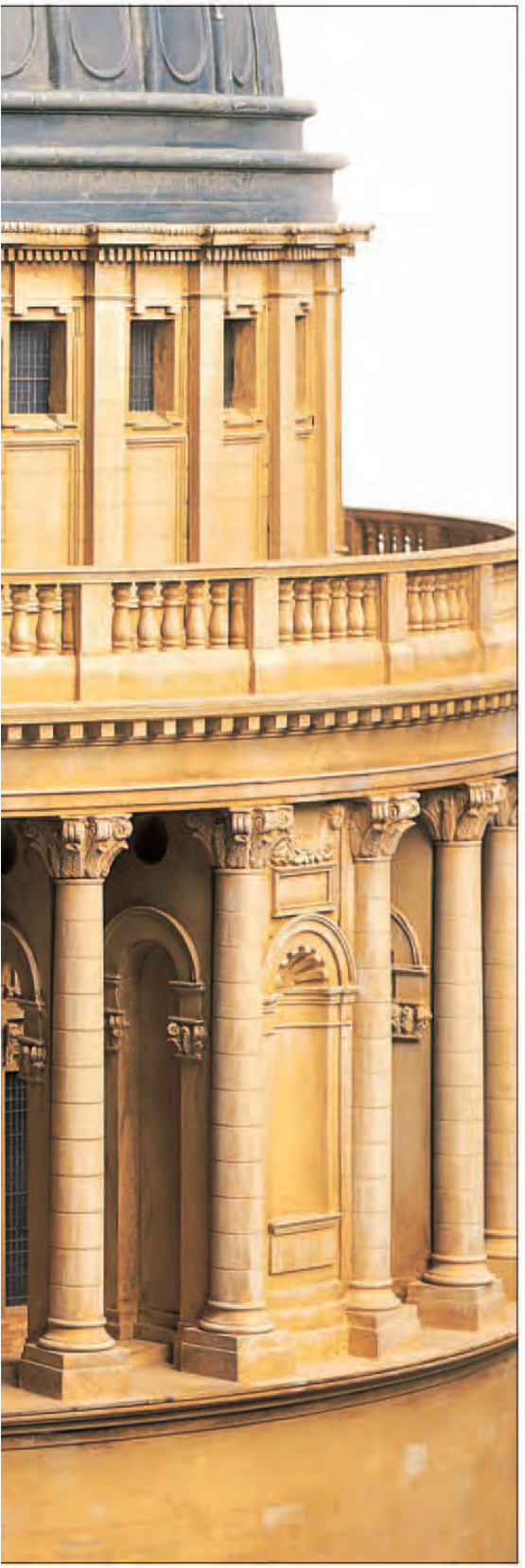


STATUE IS STRIPPED OF CLAY
When the bronze has cooled, the clay mold is broken open to reveal the bronze statue with solid metal runners and risers.

STATUE IS FINISHED
The nails are pulled out and a large hole is made to remove the plaster core. When the metal rods have been sawn off, the sculpture is filed to refine the surface.

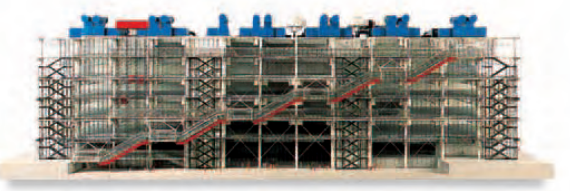
STATUE IS CLEANED
Finally, the work is cleaned and polished. An artificial patina (coloring) is achieved by treating the surface with chemicals.





Architecture

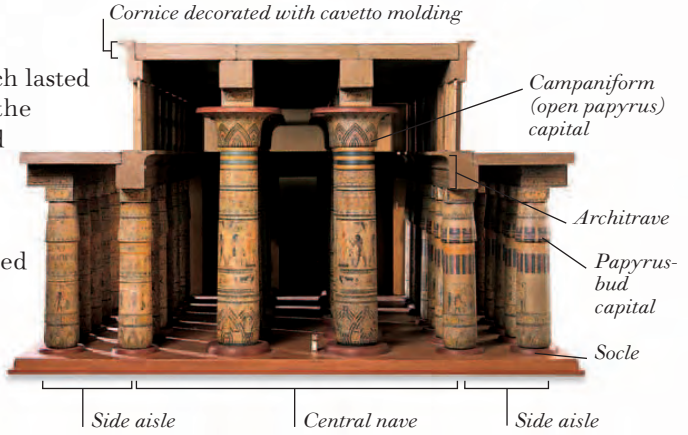
Ancient Egypt 458
Ancient Greece 460
Ancient Rome 1 462
Ancient Rome 2 464
Medieval Castles and Houses 466
Medieval Churches 468
Gothic 1 470
Gothic 2 472
Renaissance 1 474
Renaissance 2 476
Baroque and Neoclassical 1 478
Baroque and Neoclassical 2 480
Baroque and Neoclassical 3 482
Arches and Vaults 484
Domes 486
Islamic Buildings 488
South and East Asia 490
The 19th Century 492
The Early 20th Century 494
Modern Buildings 1 496
Modern Buildings 2 498



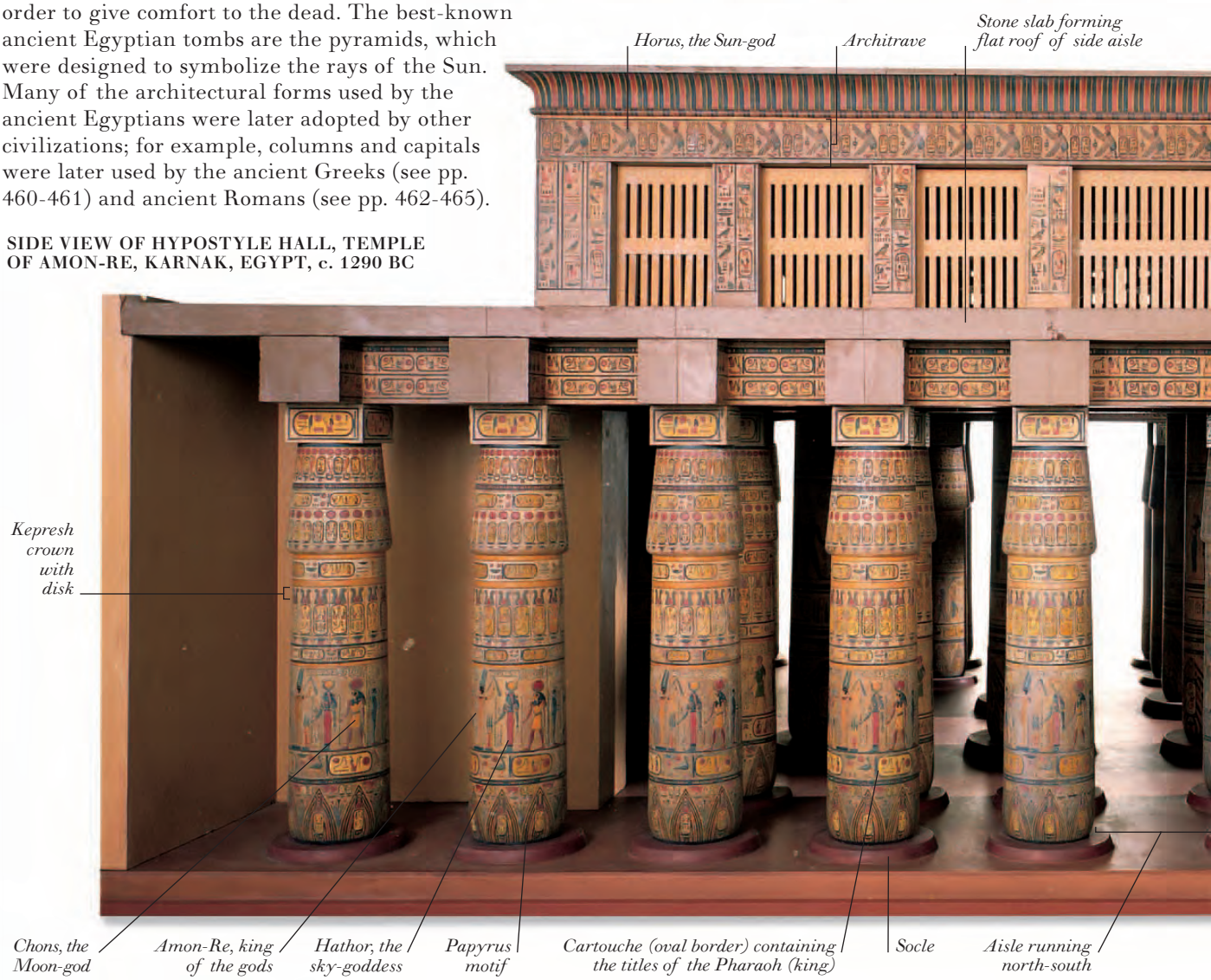
Ancient Egypt

THE CIVILIZATION OF THE ANCIENT EGYPTIANS (which lasted from about 3100 BC until it was finally absorbed into the Roman Empire in 30 BC) is famous for its temples and tombs. Egyptian temples were often huge and geometric, like the Temple of Amon-Re (below and right). They were usually decorated with hieroglyphs (sacred characters used for picture-writing) and painted reliefs depicting gods, Pharaohs (kings), and queens. Tombs were particularly important to the Egyptians, who believed that the dead were resurrected in the afterlife. The tombs were often decorated—as, for example, the surround of the false door opposite—in order to give comfort to the dead. The best-known ancient Egyptian tombs are the pyramids, which were designed to symbolize the rays of the Sun. Many of the architectural forms used by the ancient Egyptians were later adopted by other civilizations; for example, columns and capitals were later used by the ancient Greeks (see pp. 460-461) and ancient Romans (see pp. 462-465).

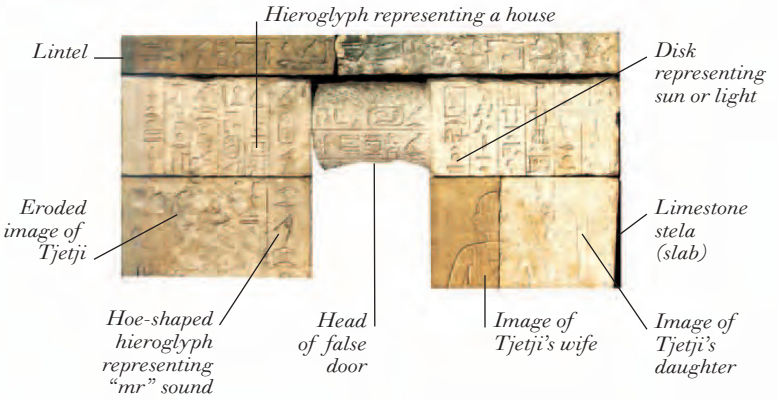
FRONT VIEW OF HYPOSTYLE HALL, TEMPLE OF AMON-RE



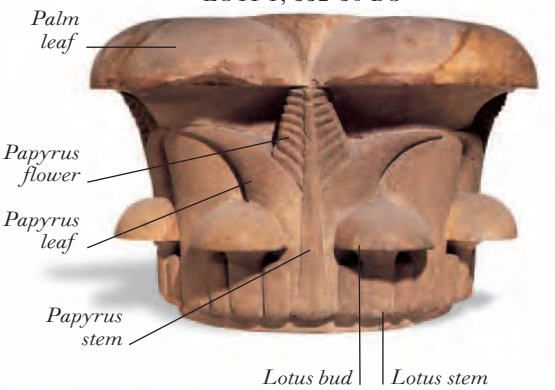
SIDE VIEW OF HYPOSTYLE HALL, TEMPLE OF AMON-RE, KARNAK, EGYPT, c. 1290 BC

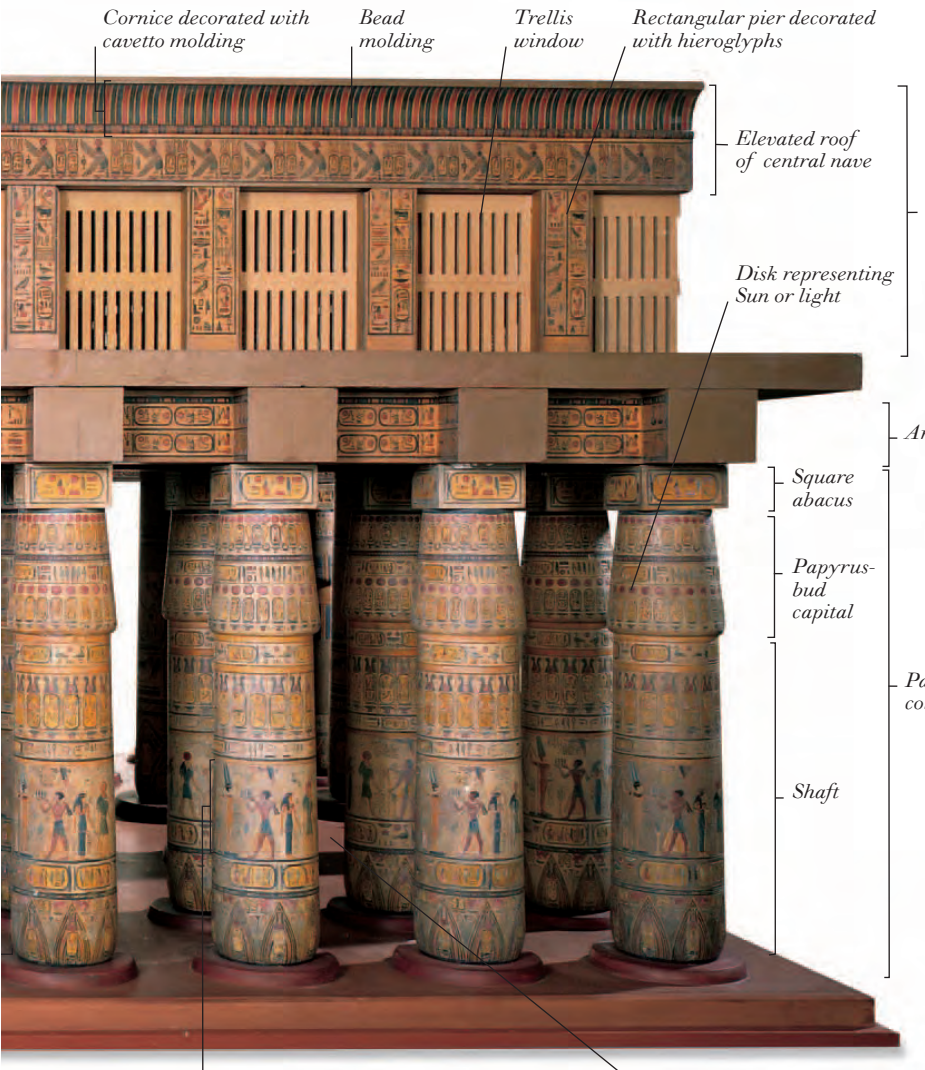


LIMESTONE FALSE DOOR WITH HIEROGLYPHS, TOMB OF KING TJETJI, GIZA, EGYPT, c.2400 BC



PLANT CAPITAL OF THE PTOLEMAIC-ROMAN PERIOD, EGYPT, 332-30 BC





ANCIENT EGYPTIAN BUILDING DECORATION

DECORATED WINDOW, MEDINET HABU, EGYPT, c.1198 BC

ROPE AND PATERAE DECORATION

CAPITAL WITH THE HEAD OF THE SKY-GODDESS HATHOR, TEMPLE OF ISIS, PHILAE, EGYPT, 283-47 BC

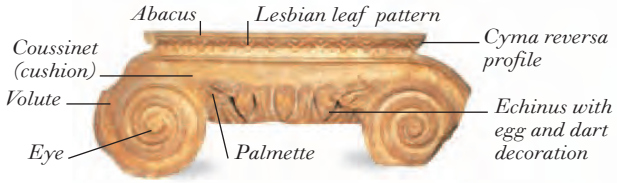
LOTUS AND PAPYRUS FRIEZE DECORATION

Ancient Greece

THE CLASSICAL TEMPLES OF ANCIENT GREECE were built according to the belief that certain forms and proportions were pleasing to the gods. There were three main ancient Greek architectural orders (styles), which can be distinguished by the decoration and proportions of their columns, capitals (column tops), and entablatures (structures resting on the capitals). The oldest is the Doric order, which dates from the seventh century BC and was used mainly on the Greek mainland and in the western colonies, such as Sicily and southern Italy. The Temple of Neptune, shown here, is a classic example of this order. It is hypaethral (roofless) and peripteral (surrounded by a single row of columns). About a century later, the more decorative Ionic order developed on the Aegean Islands. Features of this order include volutes (spiral scrolls) on capitals and acroteria (pediment ornaments). The Corinthian order was invented in Athens in the fifth century BC and is typically identified by an acanthus leaf on the capitals. This order was later widely used in ancient Roman architecture.

CAPITALS OF THE THREE ORDERS OF ANCIENT GREEK ARCHITECTURE

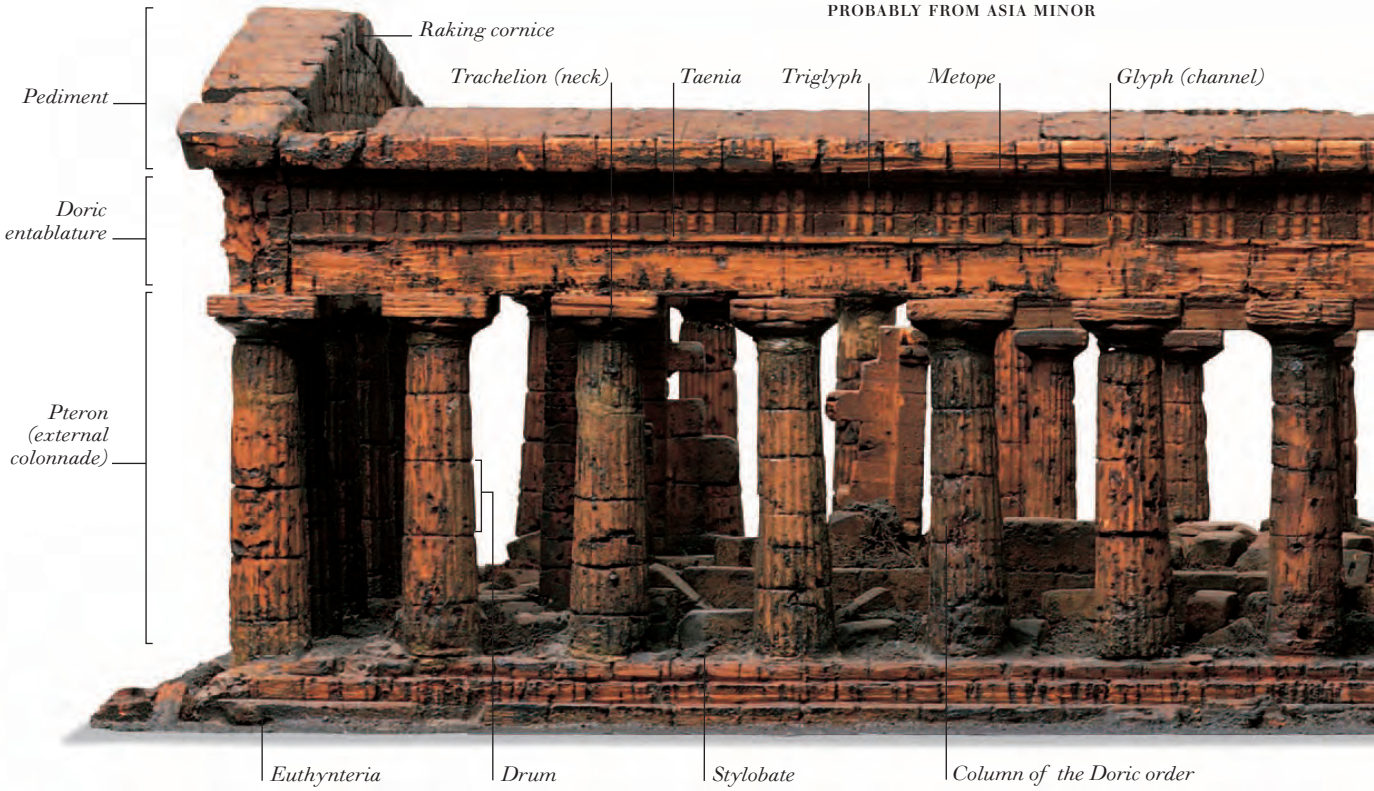
DORIC CAPITAL, THE PROPYLAEUM (GATEWAY), THE ACROPOLIS, ATHENS, GREECE, 449 BC



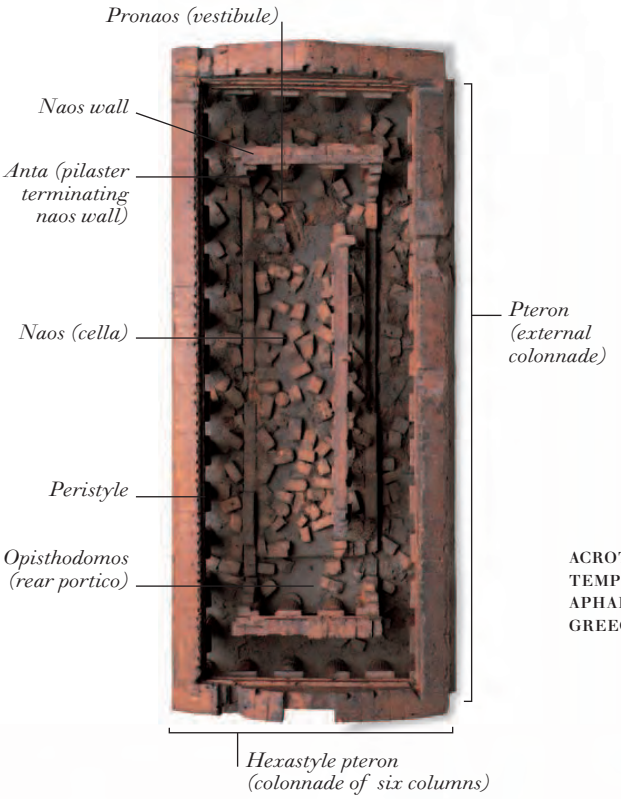
IONIC CAPITAL, THE PROPYLAEUM (GATEWAY), TEMPLE OF ATHENA POLIAS, PRIENE, GREECE, c.334 BC

CORINTHIAN CAPITAL FROM A STOA (PORTICO), PROBABLY FROM ASIA MINOR

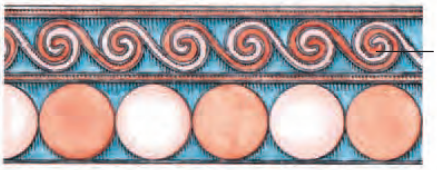
TEMPLE OF NEPTUNE, PAESTUM, ITALY, c.460 BC



PLAN OF THE TEMPLE OF NEPTUNE, PAESTUM



ANCIENT GREEK BUILDING DECORATION



FACADE, TREASURY OF ATREUS, MYCENAE, GREECE, 1350-1250 BC

FRETWORK, PARTHENON, ATHENS, GREECE, 447-436 BC

ACROTERION, TEMPLE OF APHAIA, AEGINA, GREECE, 490 BC

ANTEFIXA, TEMPLE OF APHAIA, AEGINA, GREECE, 490 BC

Ancient Rome 1

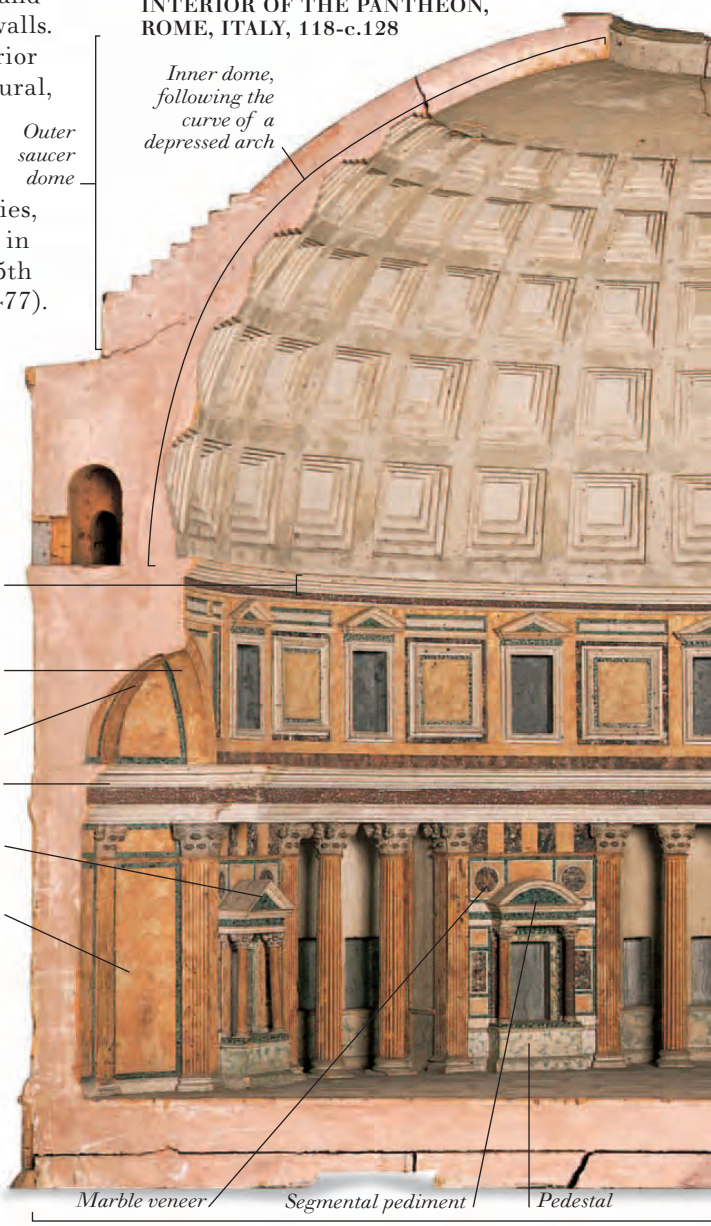
IN THE EARLY PERIOD OF THE ROMAN EMPIRE extensive use was made of ancient Greek architectural ideas, particularly those of the Corinthian order (see pp. 460-461). As a result, many early Roman buildings—such as the Temple of Vesta (opposite)—closely resemble ancient Greek buildings. A distinctive Roman style began to evolve in the first century AD. This style developed the interiors of buildings (the Greeks had concentrated on the exterior) by using arches, vaults, and domes inside the buildings, and by ornamenting internal walls. Many of these features can be seen in the Pantheon. Exterior columns were often used for decorative, rather than structural, purposes, as in the Colosseum and the Porta Nigra (see pp. 464-465). Smaller buildings had timber frames with wattle-and-daub walls, as in the mill (see pp. 464-465). Roman architecture remained influential for many centuries, with some of its principles being used in the 11th century in Romanesque buildings (see pp. 468-469) and also in the 15th and 16th centuries in Renaissance buildings (see pp. 474-477).

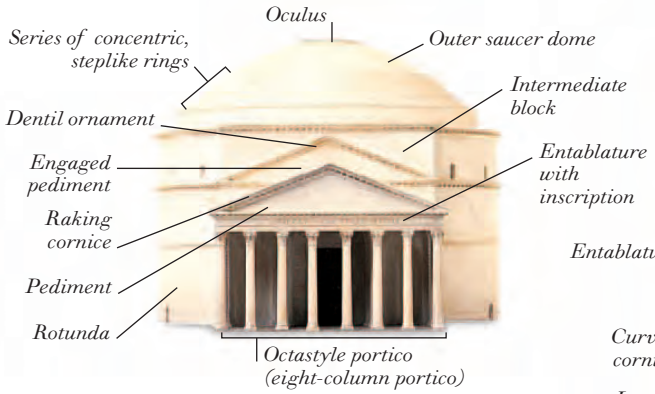
ANCIENT ROMAN BUILDING DECORATION

FESTOON, TEMPLE OF VESTA, TIVOLI, ITALY, C.80 BC

RICHLY DECORATED ROMAN OVUM

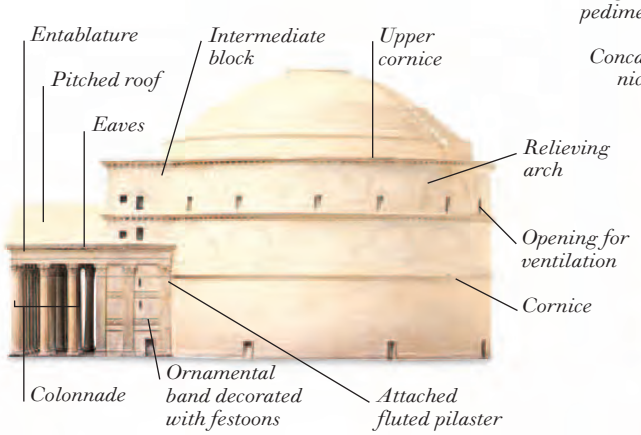
INTERIOR OF THE PANTHEON, ROME, ITALY, 118-c.128





FRONT VIEW OF THE PANTHEON

SIDE VIEW OF THE PANTHEON



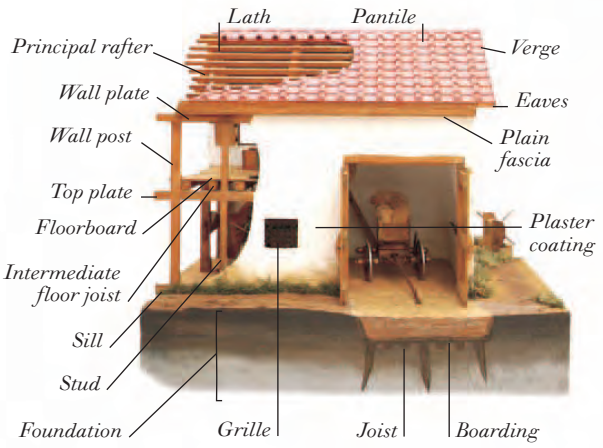
FRIEZE, FORUM OF TRAJAN, ROME, ITALY, 98-113

KEYSTONE, ARCH OF TITUS, ROME, ITALY, 81

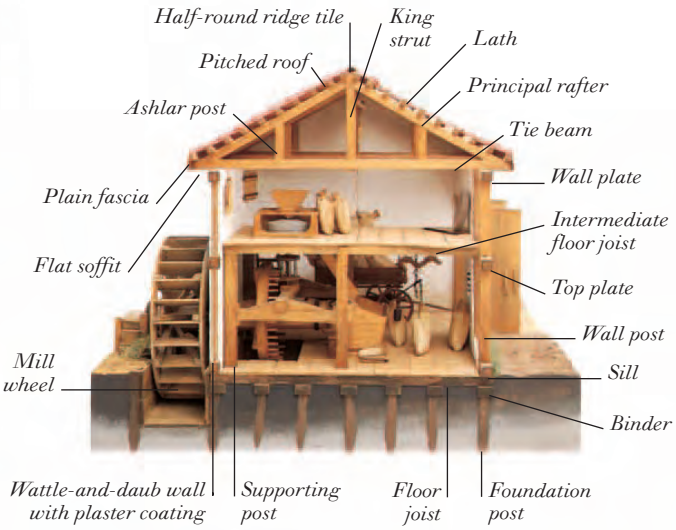
TEMPLE OF VESTA, TIVOLI, ITALY, c.80 BC

Ancient Rome 2

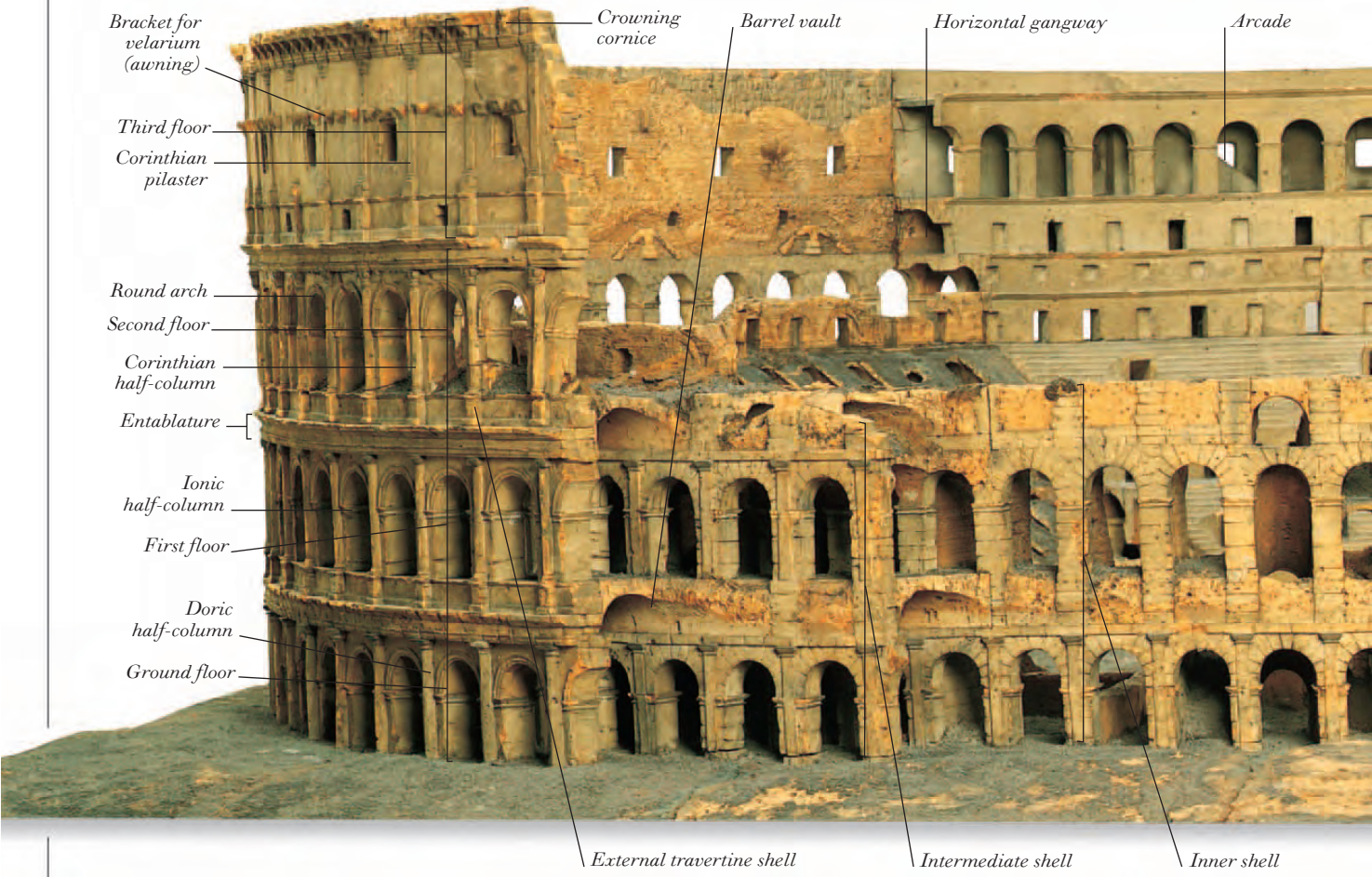
SIDE VIEW OF A ROMAN MILL



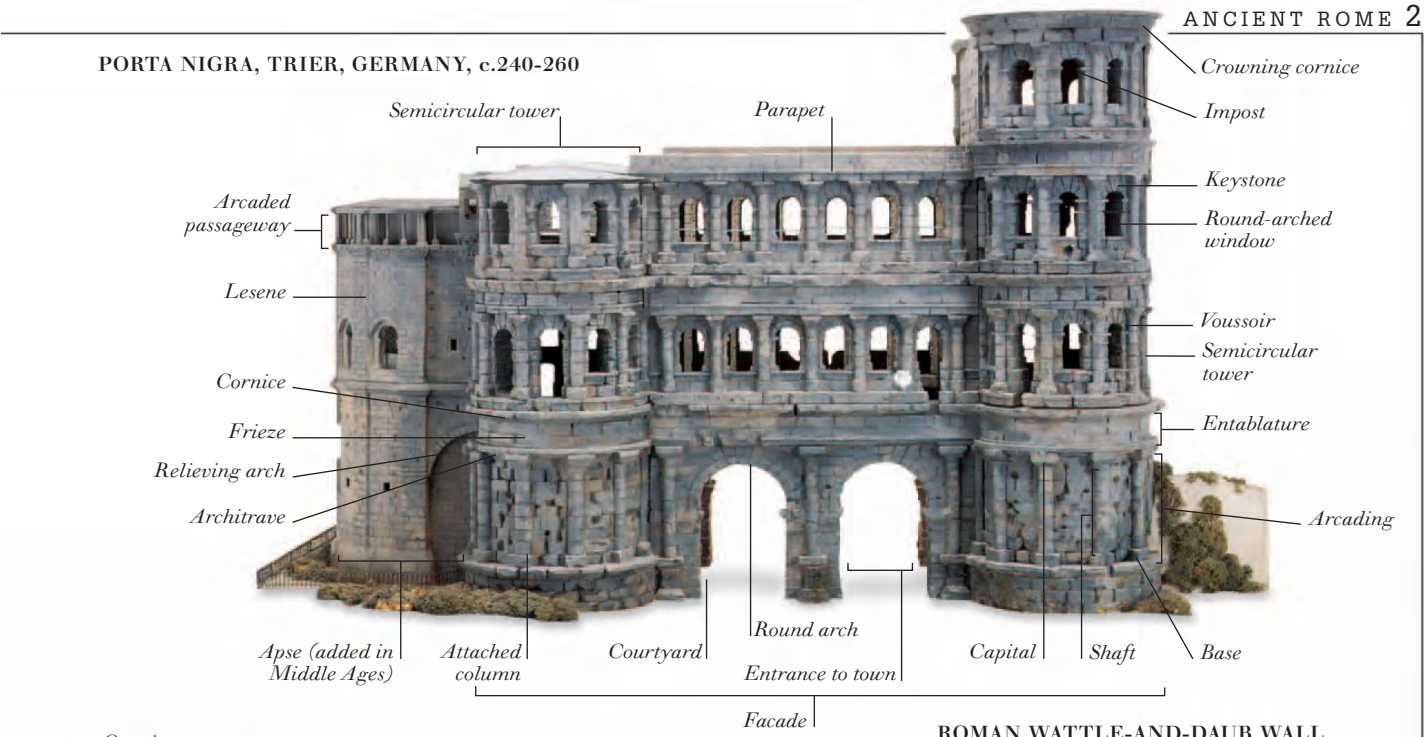
FRONT VIEW OF A ROMAN MILL, 1ST CENTURY BC



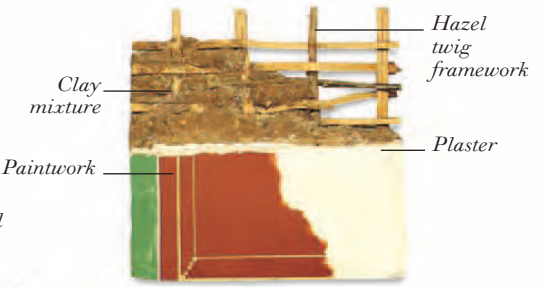
THE COLOSSEUM (FLAVIAN AMPHITHEATRE), ROME, ITALY, 70-82

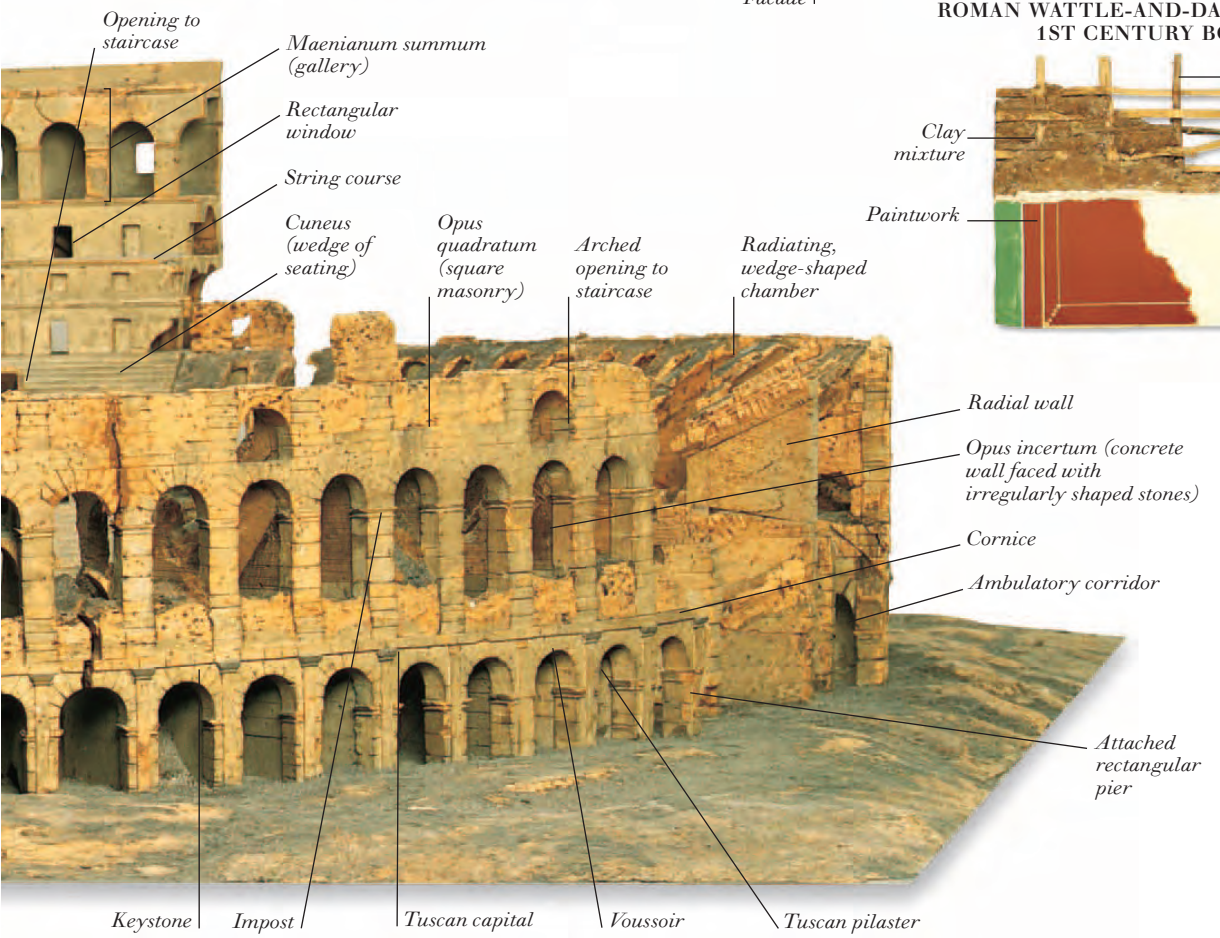


PORTA NIGRA, TRIER, GERMANY, c.240-260



ROMAN WATTLE-AND-DAUB WALL, 1ST CENTURY BC

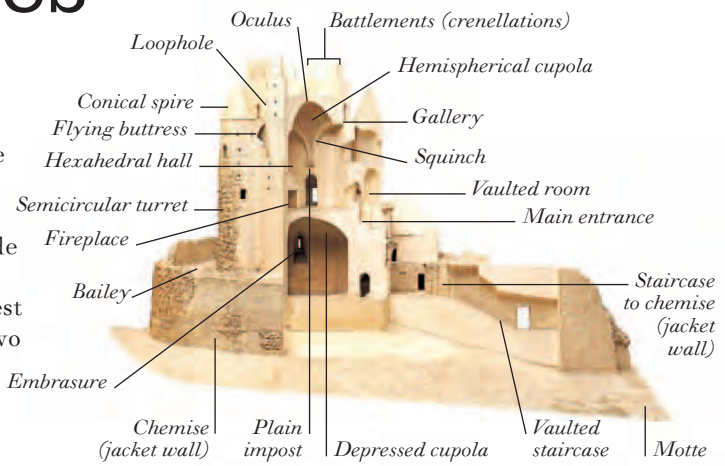


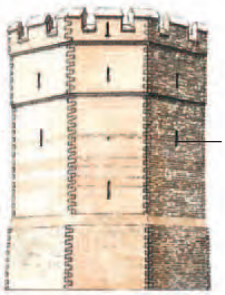


Medieval castles and houses

WARFARE WAS COMMON IN EUROPE in the Middle Ages, and many monarchs and nobles built castles as a form of defense. Typical medieval castles have outer walls surrounding a moat. Inside the moat is a bailey (courtyard), protected by a chemise (jacket wall). The innermost and strongest part of a medieval castle is the keep. There are two main types of keep: towers called donjons, such as the Tour de César and Coucy-le-Château, and rectangular keeps ("hall-keeps"), such as the Tower of London. Castles were often guarded by salients (projecting fortifications), like those of the Bastille. Medieval houses typically had timber cruck (tentlike) frames, wattle-and-daub walls, and pitched roofs, like those on medieval London Bridge (opposite).

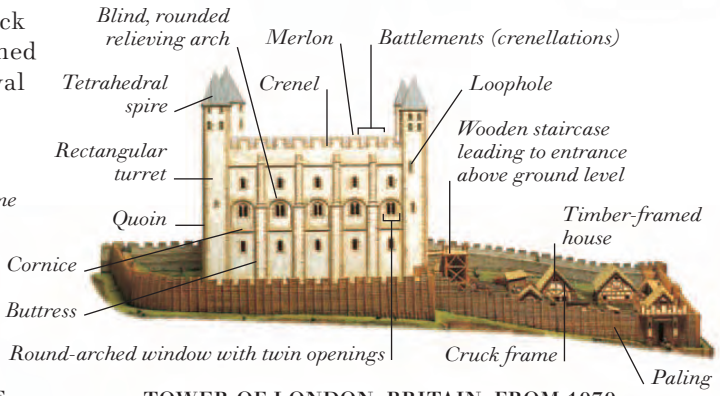
DONJON, TOUR DE CESAR, PROVINS, FRANCE, 12TH CENTURY



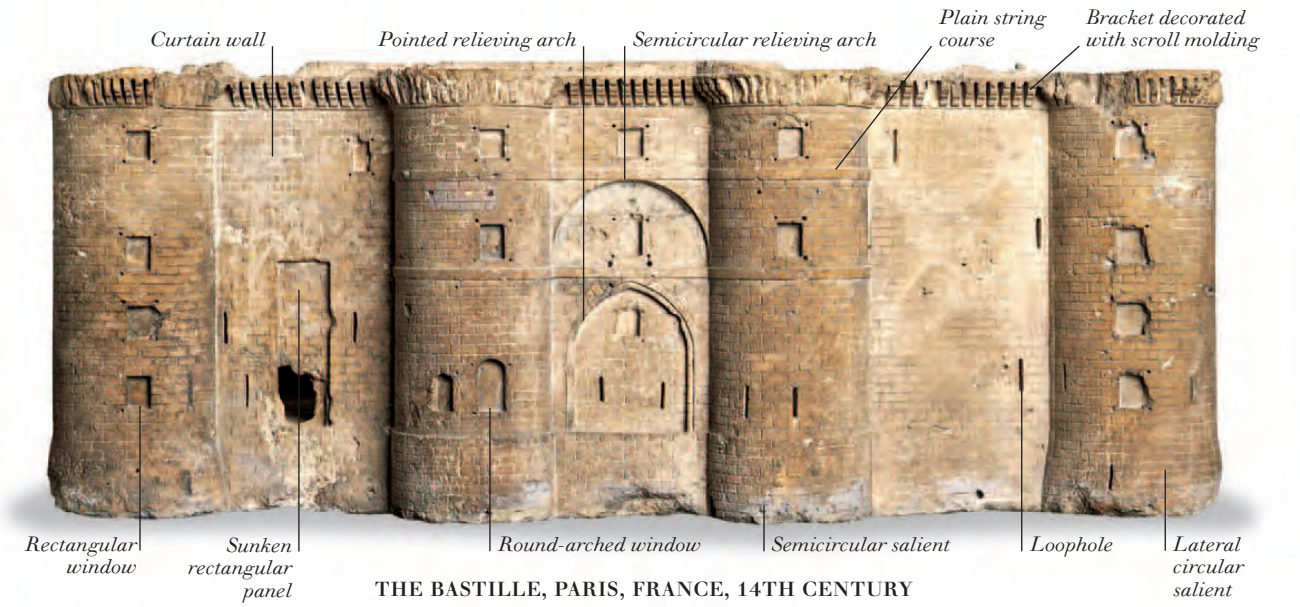


SALIENT, CAERNARVON CASTLE, BRITAIN, 1283-1323

CRUCK-FRAMED HOUSE, BRITAIN, c.1200

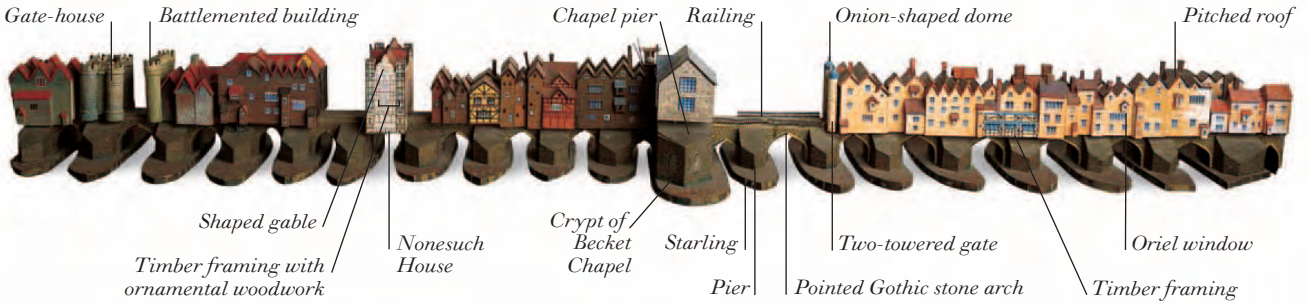


TOWER OF LONDON, BRITAIN, FROM 1070

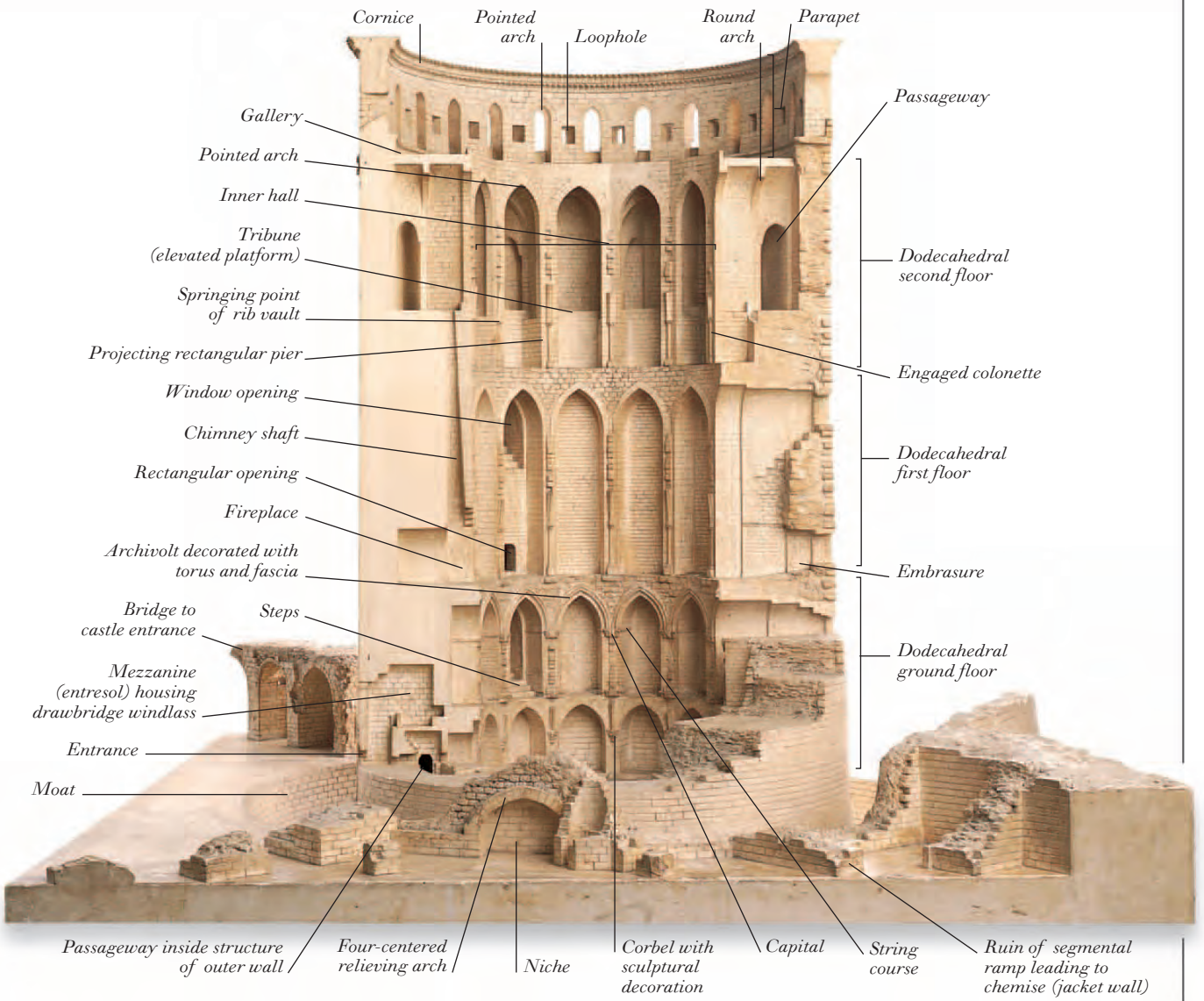


THE BASTILLE, PARIS, FRANCE, 14TH CENTURY

MEDIEVAL LONDON BRIDGE, BRITAIN, 1176 (WITH 14TH-CENTURY BATTLEMENTED BUILDING, NONESUCH HOUSE, AND TWO-TOWERED GATE)



DONJON, COUCY-LE-CHATEAU, AISNE, FRANCE, 1225-1245



Medieval churches

DURING THE MIDDLE AGES, large numbers of churches were built in Europe. European churches of this period typically have high vaults supported by massive piers and columns. In the 10th century, the Romanesque style developed. Romanesque architects adopted many Roman or early Christian architectural ideas, such as cross-shaped ground-plans—like that of Angoulême Cathedral (opposite)—and the basilican system of a nave with a central vessel and side aisles. In the mid-12th century, flying buttresses and pointed vaults appeared. These features later became widely used in Gothic architecture (see pp. 470-471). Bagneux Church (opposite) has both styles: a Romanesque tower, and a Gothic nave and choir.

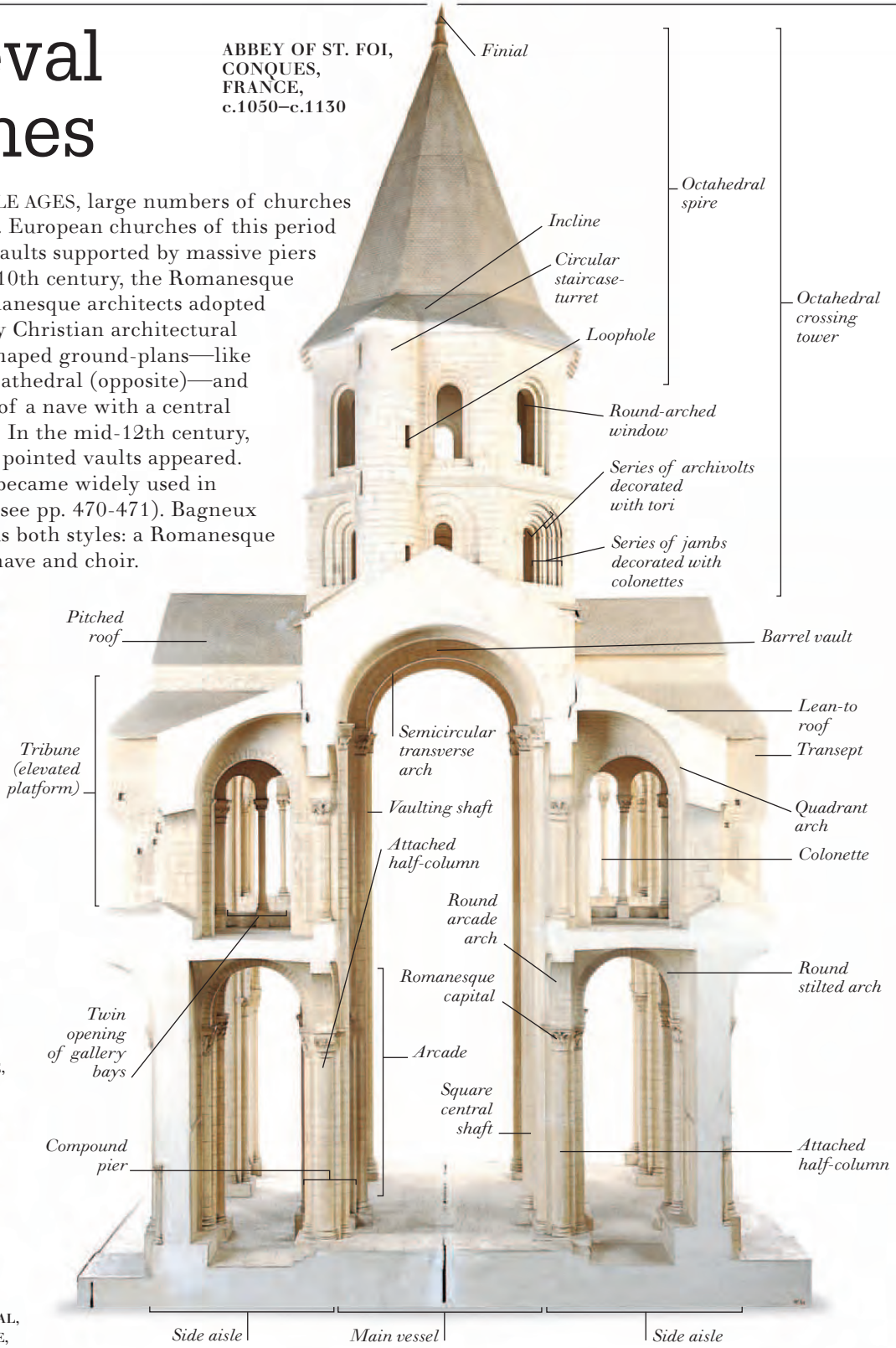
CHURCH-ROOF BOSS, BRITAIN

ROMANESQUE CAPITALS

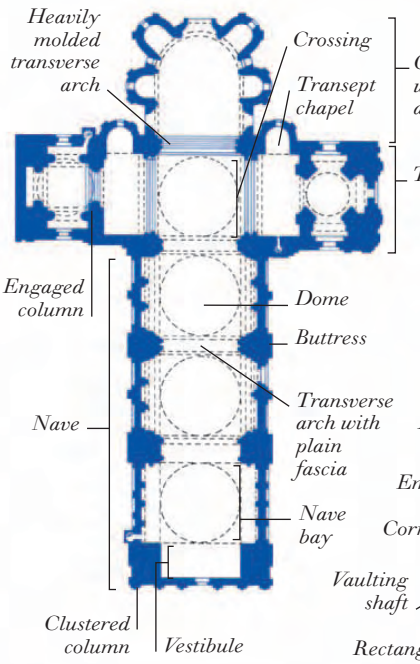
"THE FLIGHT INTO EGYPT" CAPITAL, CATHEDRAL OF ST. LAZARE, AUTUN, FRANCE, 1120-1130

"CHRIST IN MAJESTY" CAPITAL, BASILICA OF ST. MADELEINE, VEZELAY, FRANCE, 1120-1140

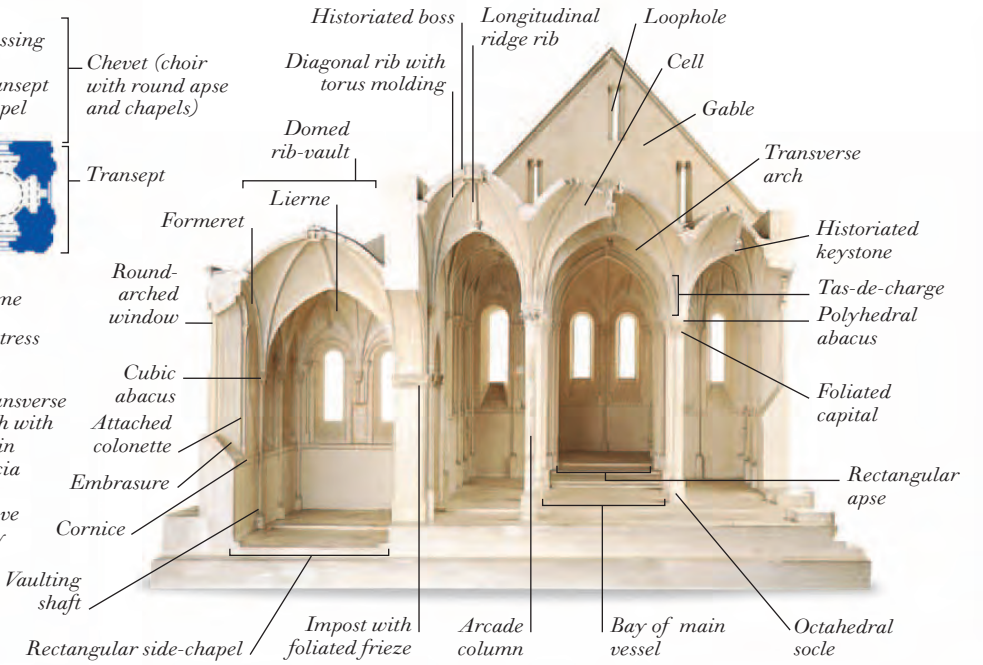
ABBEY OF ST. FOI, CONQUES, FRANCE, c.1050–c.1130



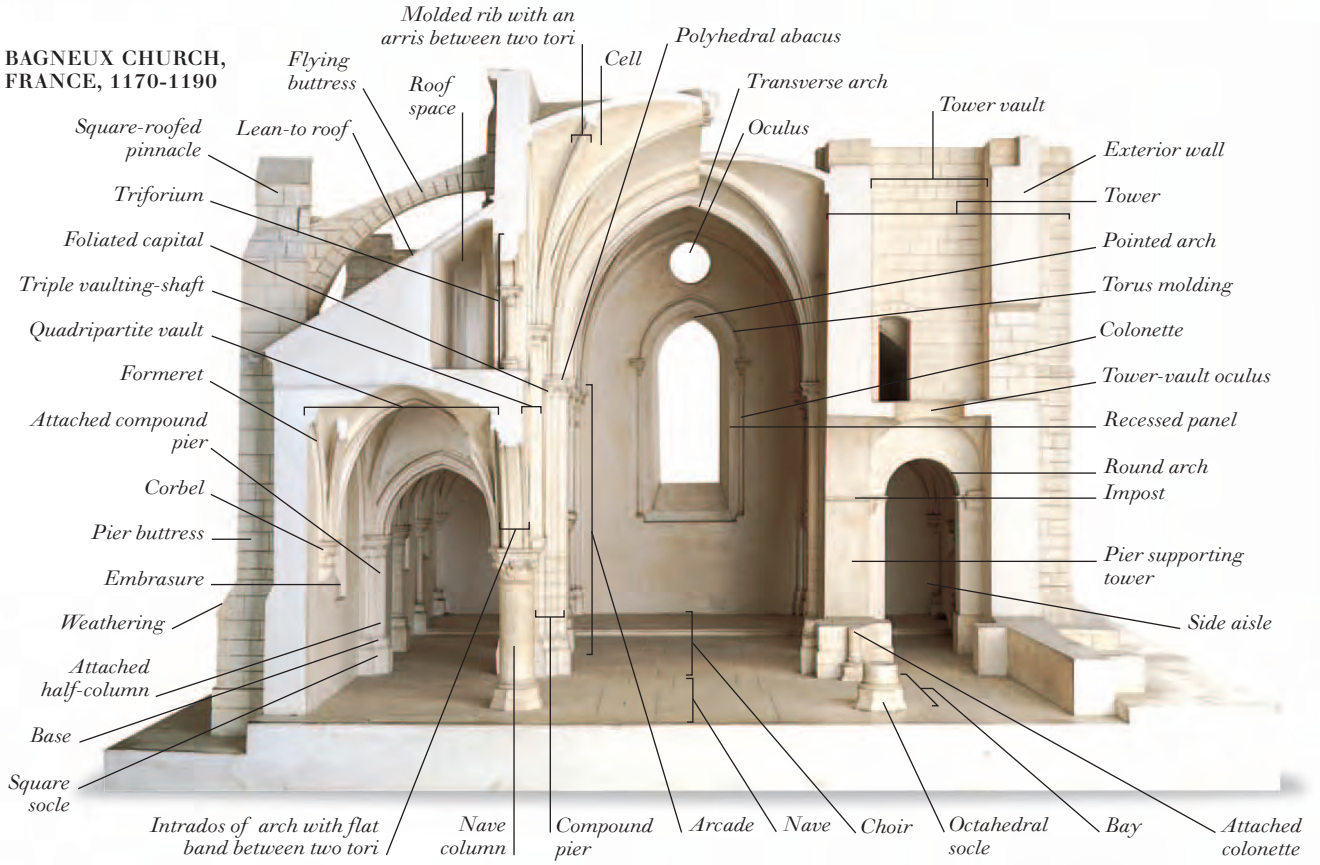
GROUND-PLAN OF ANGOULEME CATHEDRAL, FRANCE, FROM c.1105



CHOIR, CHURCH OF ST. SERGE, ANGERS, FRANCE, c.1215-1220



BAGNEUX CHURCH, FRANCE, 1170-1190

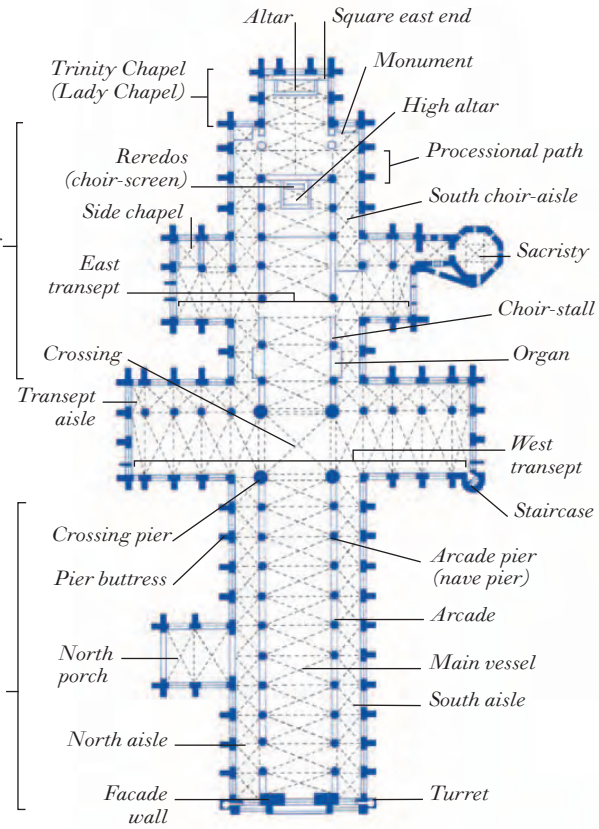


Gothic 1

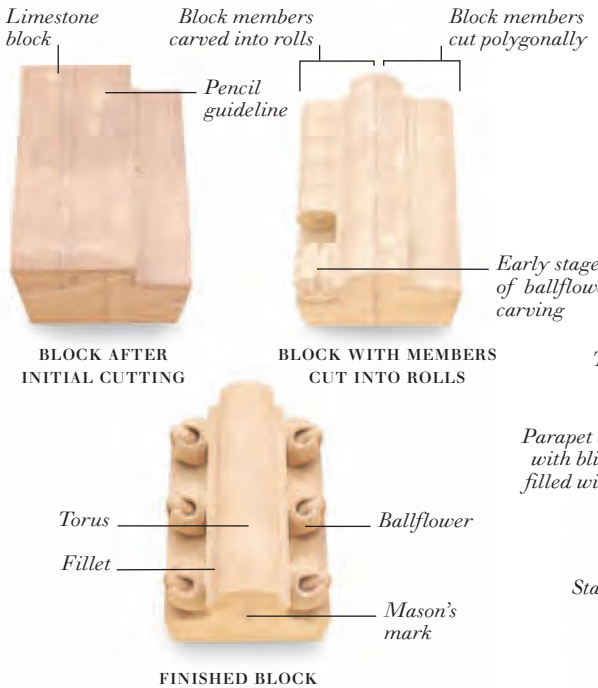
GOTHIC STAINED GLASS WITH FOLIATED SCROLL MOTIF, ON WOODEN FORM

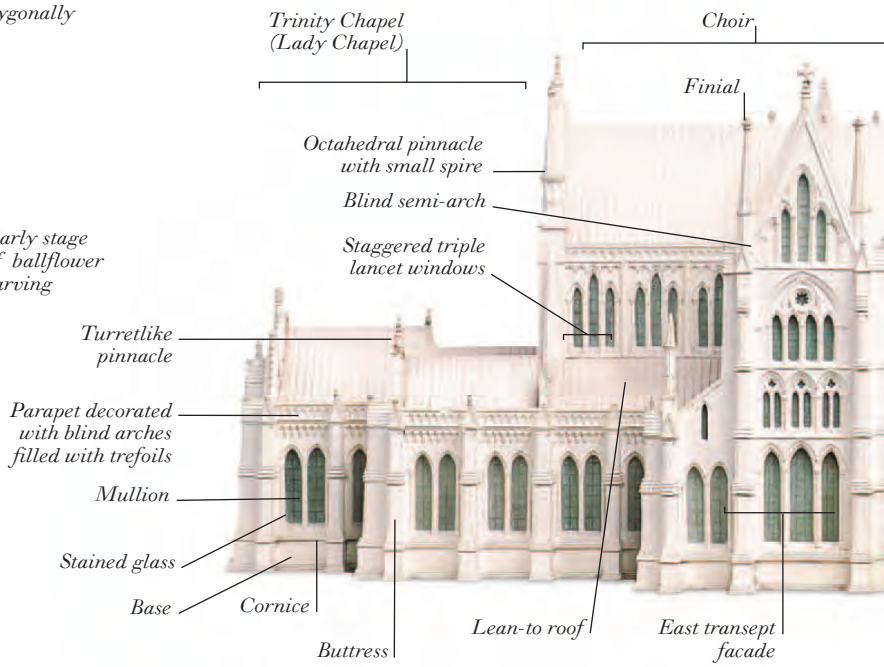
GOTHIC BUILDINGS are characterized by rib vaults, pointed or lancet arches, flying buttresses, decorative tracery and gables, and stained-glass windows. Typical Gothic buildings include the Cathedrals of Salisbury and old St. Paul's in England, and Notre Dame de Paris in France (see pp. 472-473). The Gothic style developed out of Romanesque architecture in France (see pp. 468-469) in the mid-12th century, and then spread throughout Europe. The decorative elements of Gothic architecture became highly developed in buildings of the English Decorated style (late 13th-14th century) and the French Flamboyant style (15th-16th century). These styles are exemplified by the tower of Salisbury Cathedral and the staircase in the Church of St. Maclou (see pp. 472-473), respectively. In both of these styles, embellishments such as ballflowers and curvilinear (flowing) tracery were used liberally. The English Perpendicular style (late 14th-15th century), which followed the Decorated style, emphasized the vertical and horizontal elements of a building. A notable feature of this style is the hammer-beam roof.

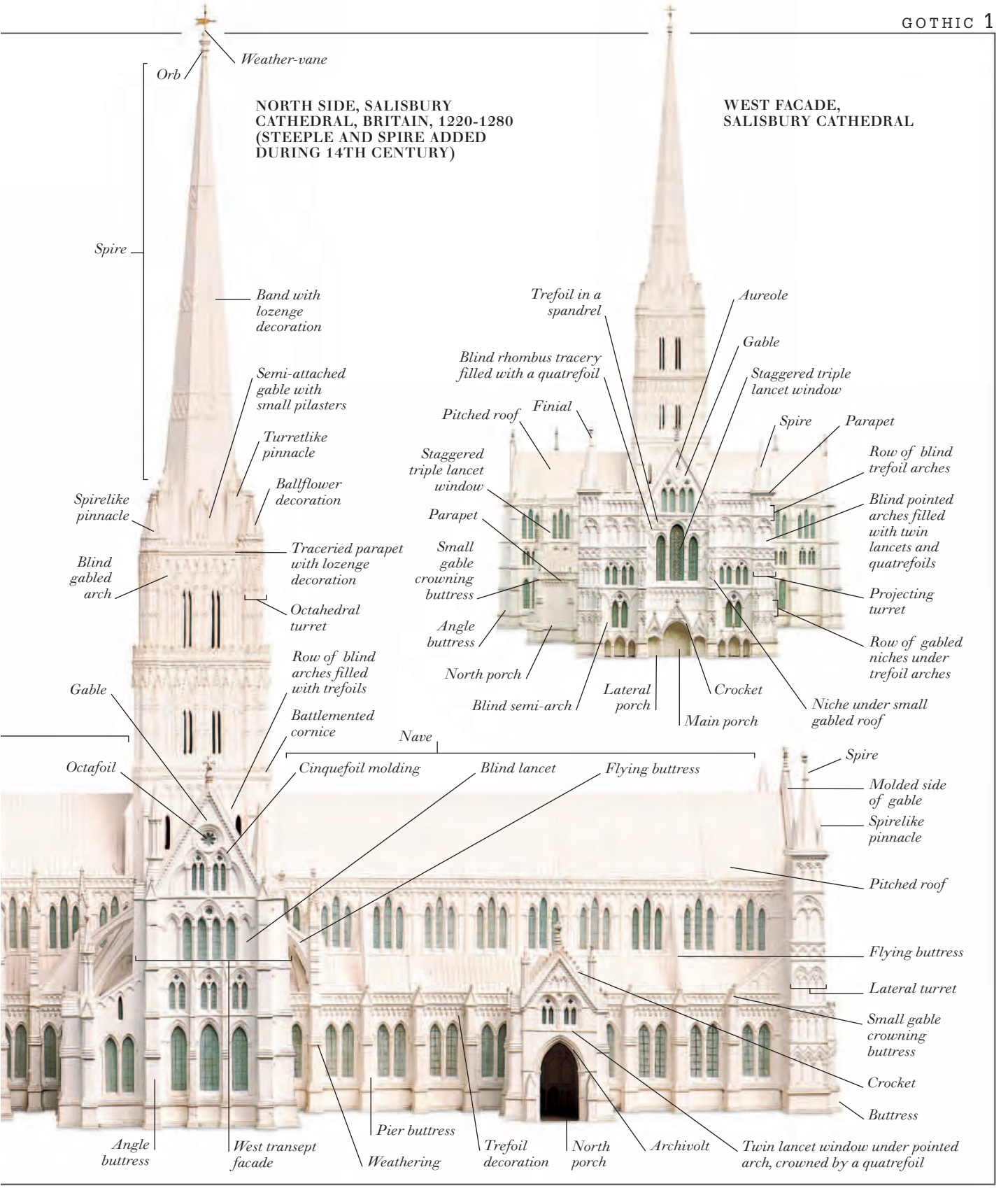
GROUND-PLAN OF SALISBURY CATHEDRAL



GOTHIC TORUS WITH BALLFLOWERS





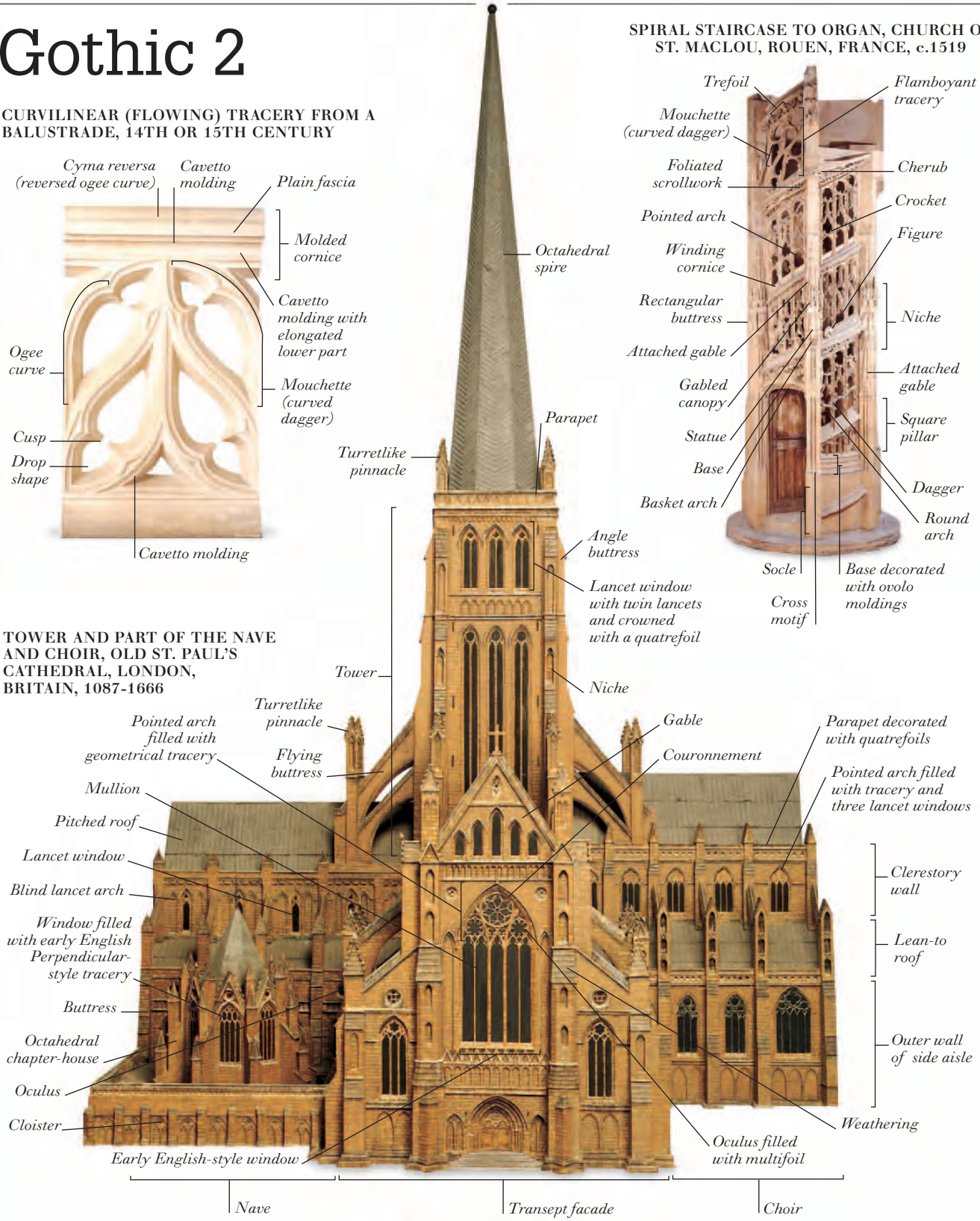

NORTH SIDE, SALISBURY CATHEDRAL, BRITAIN, 1220-1280 (STEEPLE AND SPIRE ADDED DURING 14TH CENTURY)
WEST FACADE, SALISBURY CATHEDRAL
Weather-vane
Orb
Spire
Band with lozenge decoration
Semi-attached gable with small pilasters
Turretlike pinnacle
Ballflower decoration
Spirelike pinnacle
Traceried parapet with lozenge decoration
Blind gabled arch
Octahedral turret
Row of blind arches filled with trefoils
Gable
Battlemented cornice
Octafoil
Cinquefoil molding
Nave
Blind lancet
Flying buttress
Angle buttress
West transept facade
Pier buttress
Weathering
Trefoil decoration
North porch
Archivolt
Twin lancet window under pointed arch, crowned by a quatrefoil
Buttress
Crocket
Small gable crowning buttress
Lateral turret
Flying buttress
Pitched roof
Molded side of gable
Spirelike pinnacle
Spire
Trefoil in a spandrel
Aureole
Gable
Blind rhombus tracery filled with a quatrefoil
Staggered triple lancet window
Pitched roof
Finial
Spire
Parapet
Staggered triple lancet window
Row of blind trefoil arches
Parapet
Blind pointed arches filled with twin lancets and quatrefoils
Small gable crowning buttress
Projecting turret
Angle buttress
Row of gabled niches under trefoil arches
North porch
Blind semi-arch
Lateral porch
Crocket
Main porch
Niche under small gabled roof

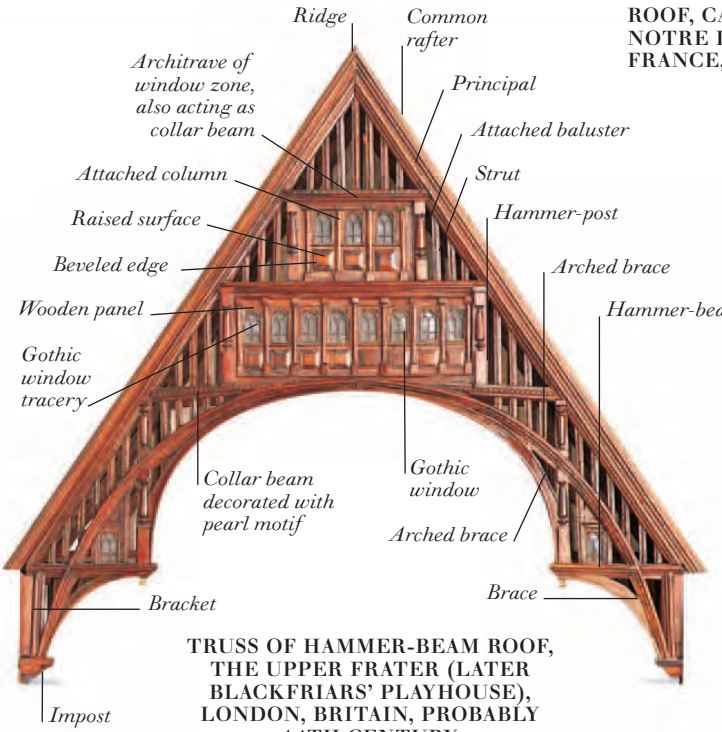
Gothic 2

CURVILINEAR (FLOWING) TRACERY FROM A BALUSTRADE, 14TH OR 15TH CENTURY

SPIRAL STAIRCASE TO ORGAN, CHURCH OF ST. MACLOU, ROUEN, FRANCE, c.1519

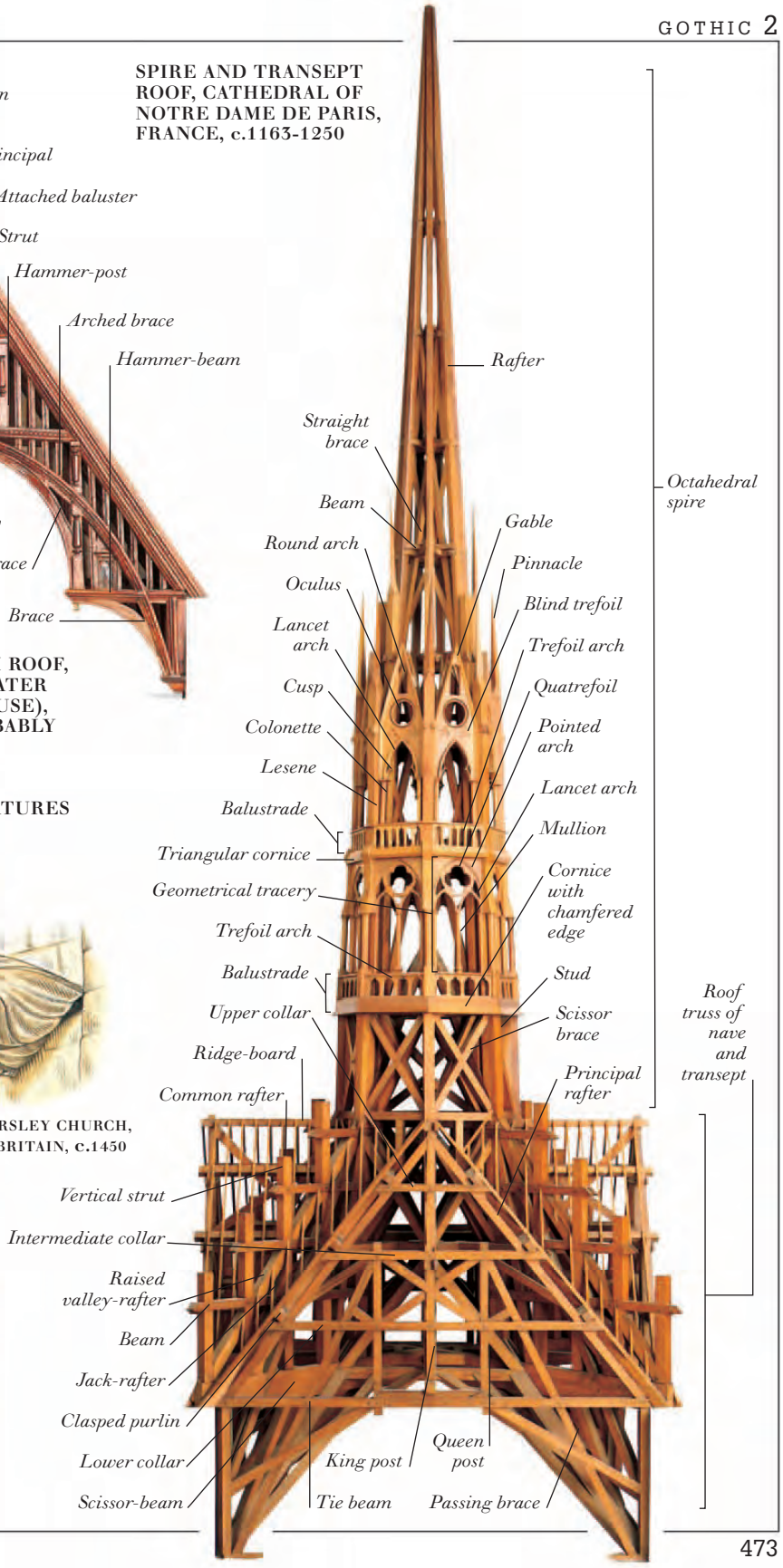
TOWER AND PART OF THE NAVE AND CHOIR, OLD ST. PAUL'S CATHEDRAL, LONDON, BRITAIN, 1087-1666



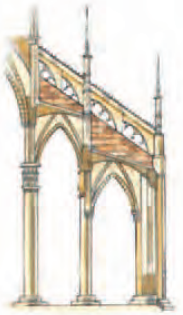


TRUSS OF HAMMER-BEAM ROOF, THE UPPER FRATER (LATER BLACKFRIARS' PLAYHOUSE), LONDON, BRITAIN, PROBABLY 14TH CENTURY

SPIRE AND TRANSEPT ROOF, CATHEDRAL OF NOTRE DAME DE PARIS, FRANCE, c.1163-1250



TYPICAL GOTHIC FEATURES



FLYING BUTTRESS OVER SIDE AISLES, MILAN CATHEDRAL, ITALY, c.1385-1485

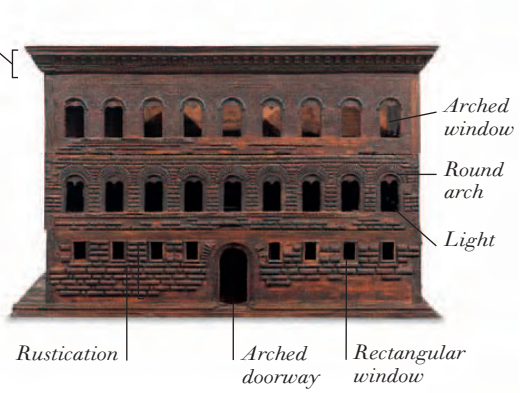
GARGOYLE, HORSLEY CHURCH, DERBYSHIRE, BRITAIN, c.1450

HAMMER-BEAM ROOF, CHURCH OF ST. BOTOLPH, TRUNCH, NORFOLK, BRITAIN, 1360-1380

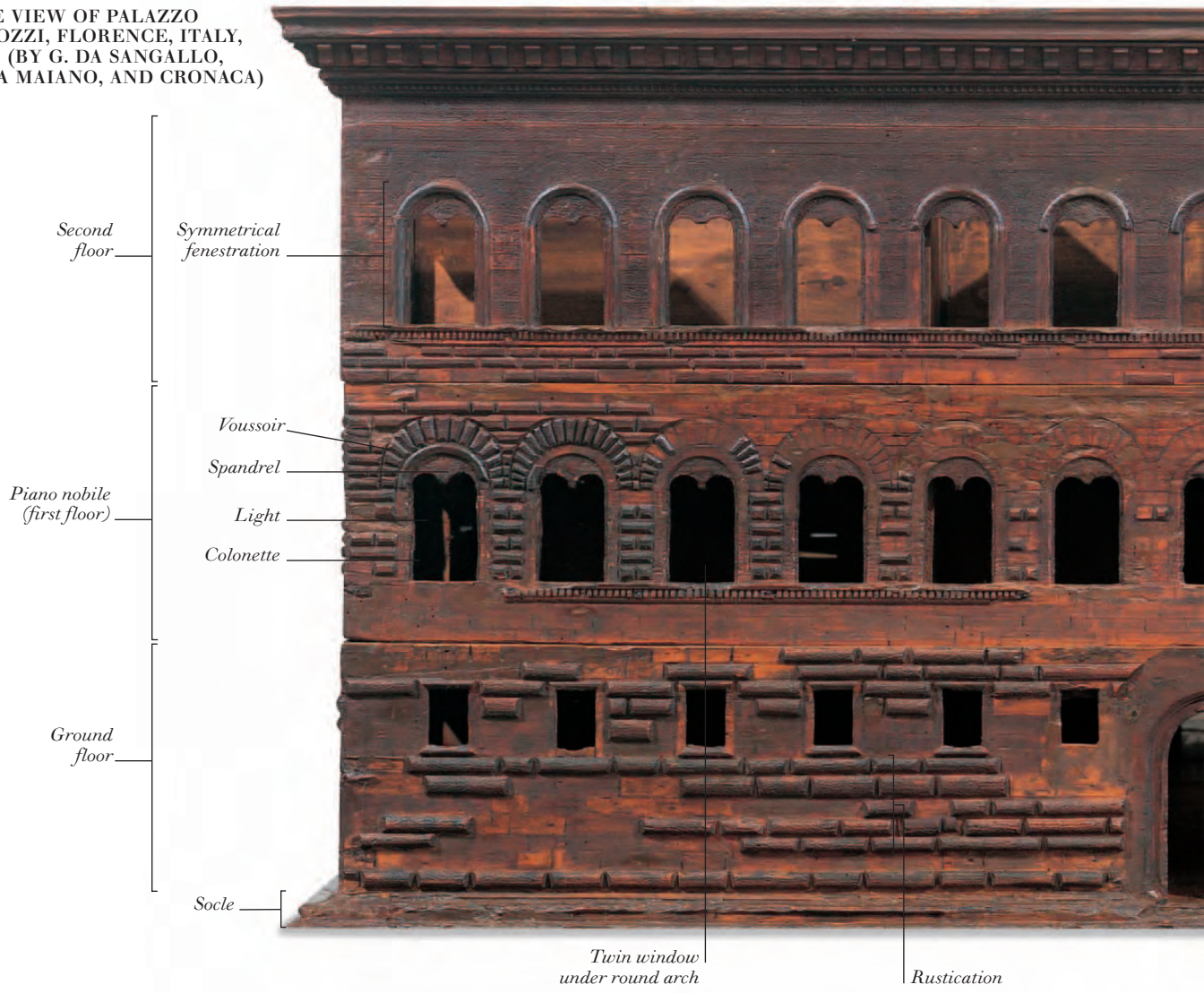
Renaissance 1

THE RENAISSANCE was a European movement—lasting roughly from the 14th century to the mid-17th century—in which the arts and sciences underwent great changes. In architecture, these changes were marked by a return to the classical forms and proportions of ancient Roman buildings. The Renaissance originated in Italy, and the buildings most characteristic of its style can be found there, such as the Palazzo Strozzi shown here. Mannerism is a branch of the Renaissance style that distorts the classical forms; an example is the Laurentian Library staircase. As the Renaissance style spread to other European countries, many of its features were incorporated into the local architecture; for example, the Château de Montal in France (see pp. 476-477) incorporates aedicules (tabernacles).

FACADE ON TO PIAZZA, PALAZZO STROZZI



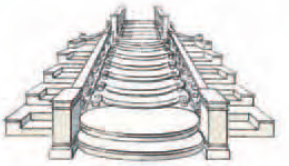
SIDE VIEW OF PALAZZO STROZZI, FLORENCE, ITALY, 1489 (BY G. DA SANGALLO, B. DA MAIANO, AND CRONACA)



DETAILS FROM ITALIAN RENAISSANCE BUILDINGS

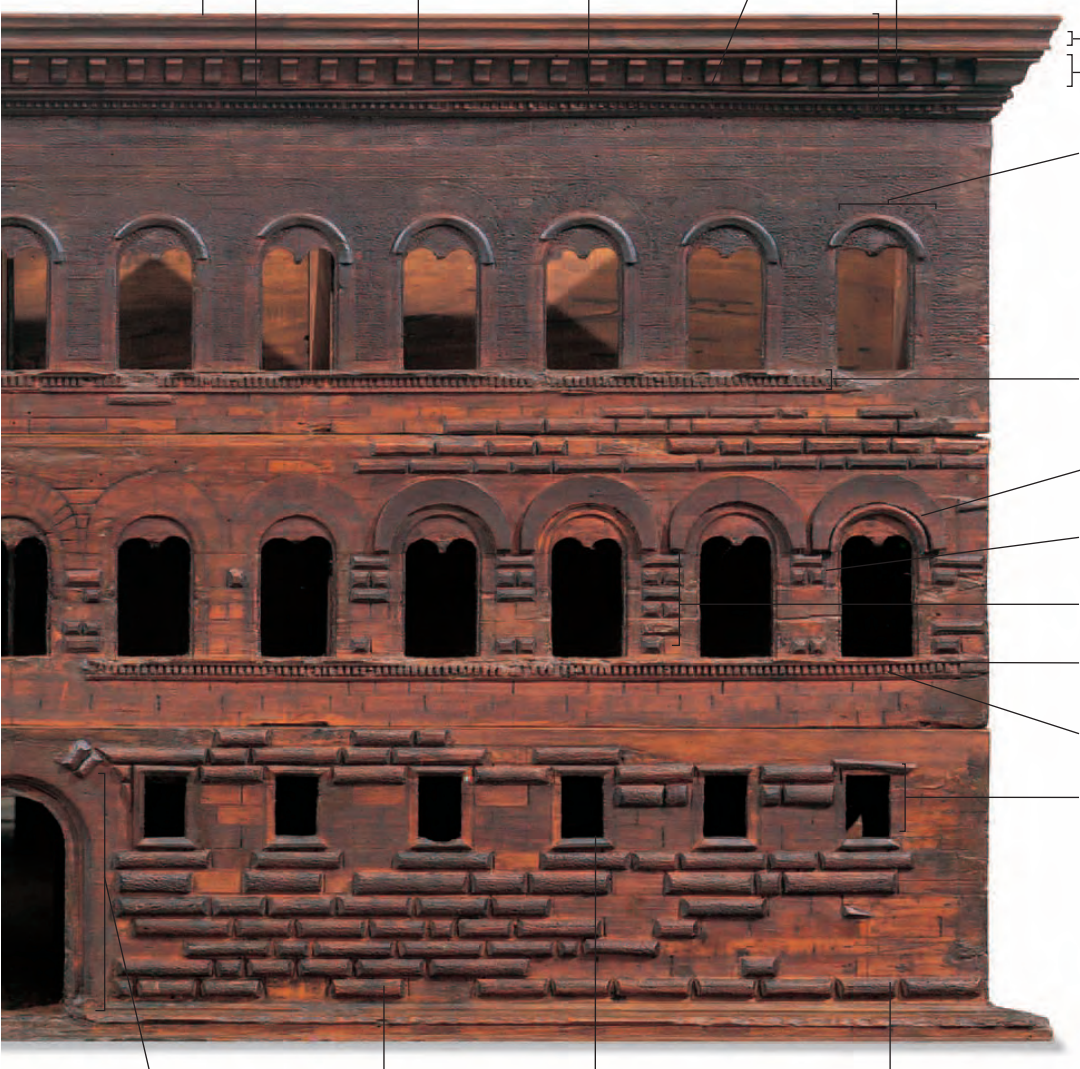
PANEL FROM DRUM OF DOME,
FLORENCE CATHEDRAL, 1420-1436

COFFERING IN DOME,
PAZZI CHAPEL,
FLORENCE, 1429-1461



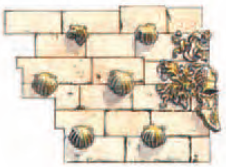
STAIRCASE,
LAURENTIAN LIBRARY,
FLORENCE, 1559

PORTICO, VILLA ROTUNDA,
VICENZA, 1567-1569



Renaissance 2

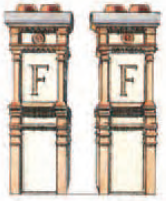
DETAILS FROM EUROPEAN RENAISSANCE BUILDINGS



STONE WALL, QUOINS, AND SHELL DECORATION, CASA DE LAS CONCHAS, SALAMANCA, SPAIN, 1475-1483

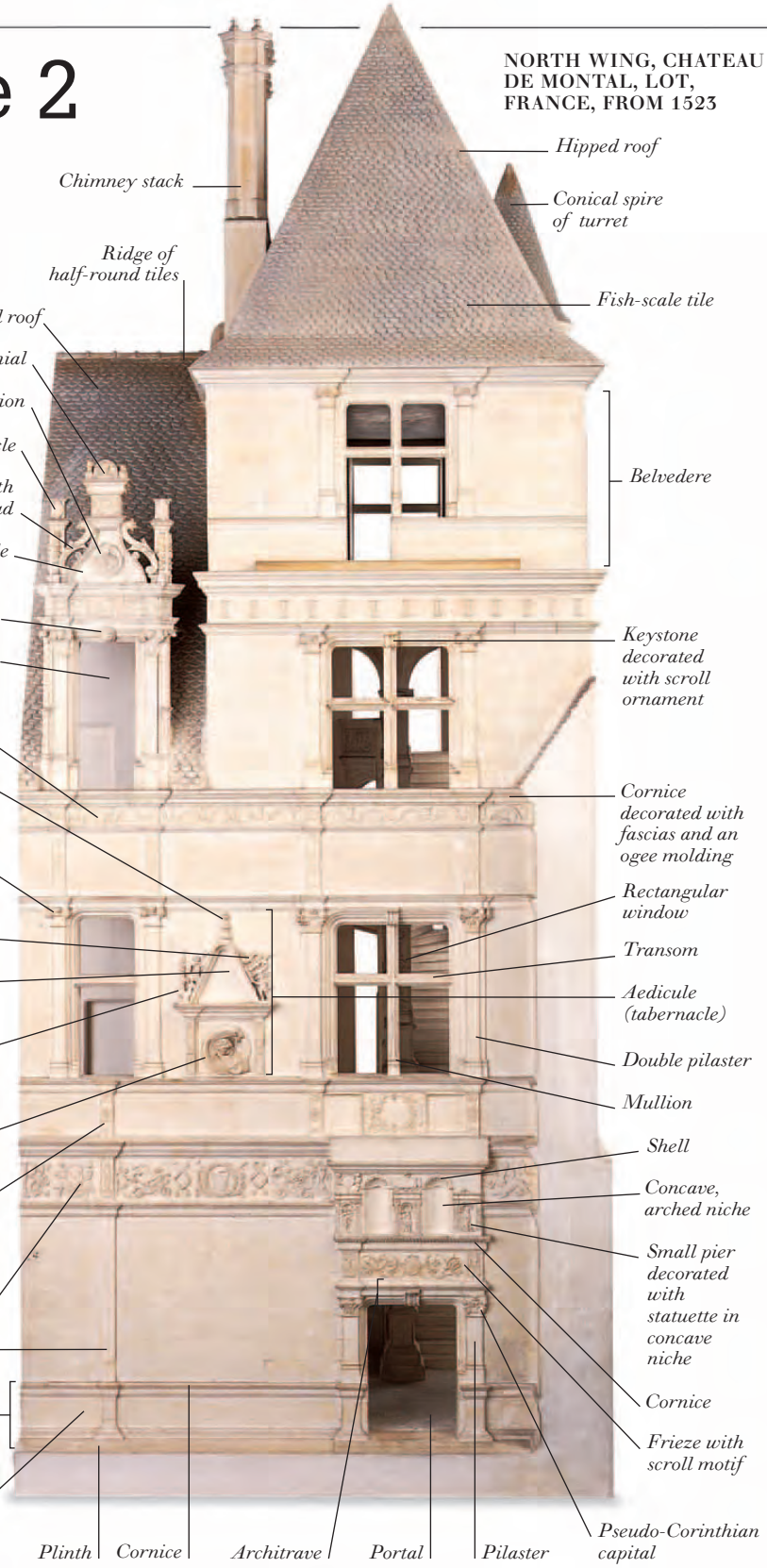
SPIRAL-STAIRCASE TOWER, CHATEAU DE BLOIS, FRANCE, 1514-1530

CONICAL DOME, CHATEAU DE CHAMBORD, FRANCE, 1519-1547

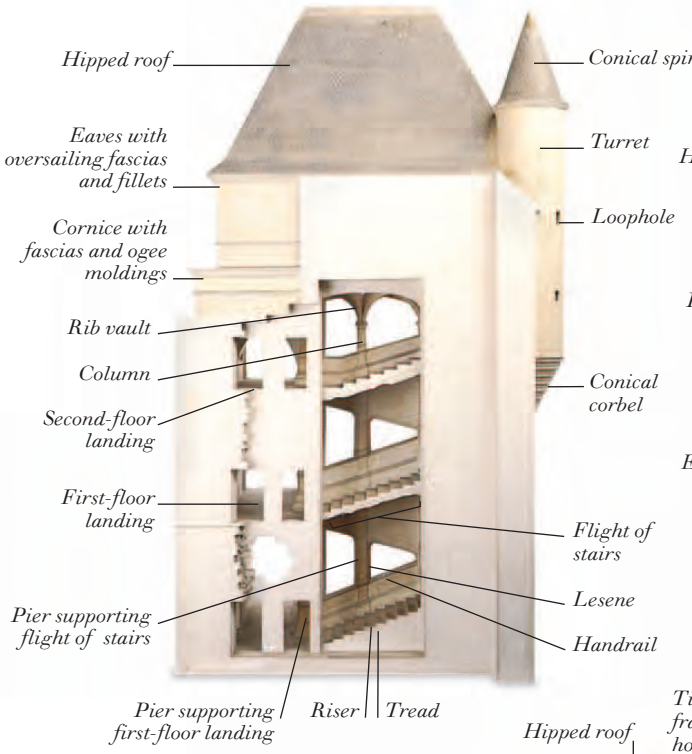


PAIR OF CHIMNEY-STACKS, PALAIS DE FONTAINEBLEAU, FRANCE, FROM 1528

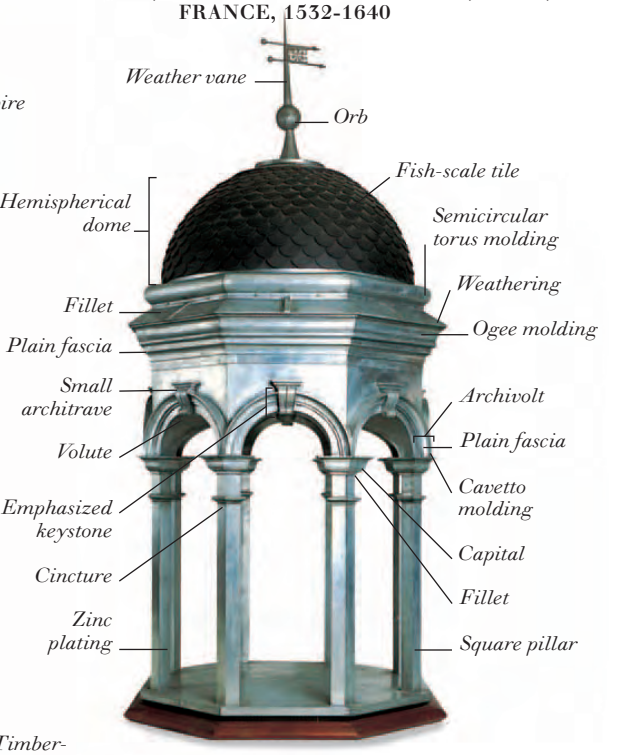
NORTH WING, CHATEAU DE MONTAL, LOT, FRANCE, FROM 1523



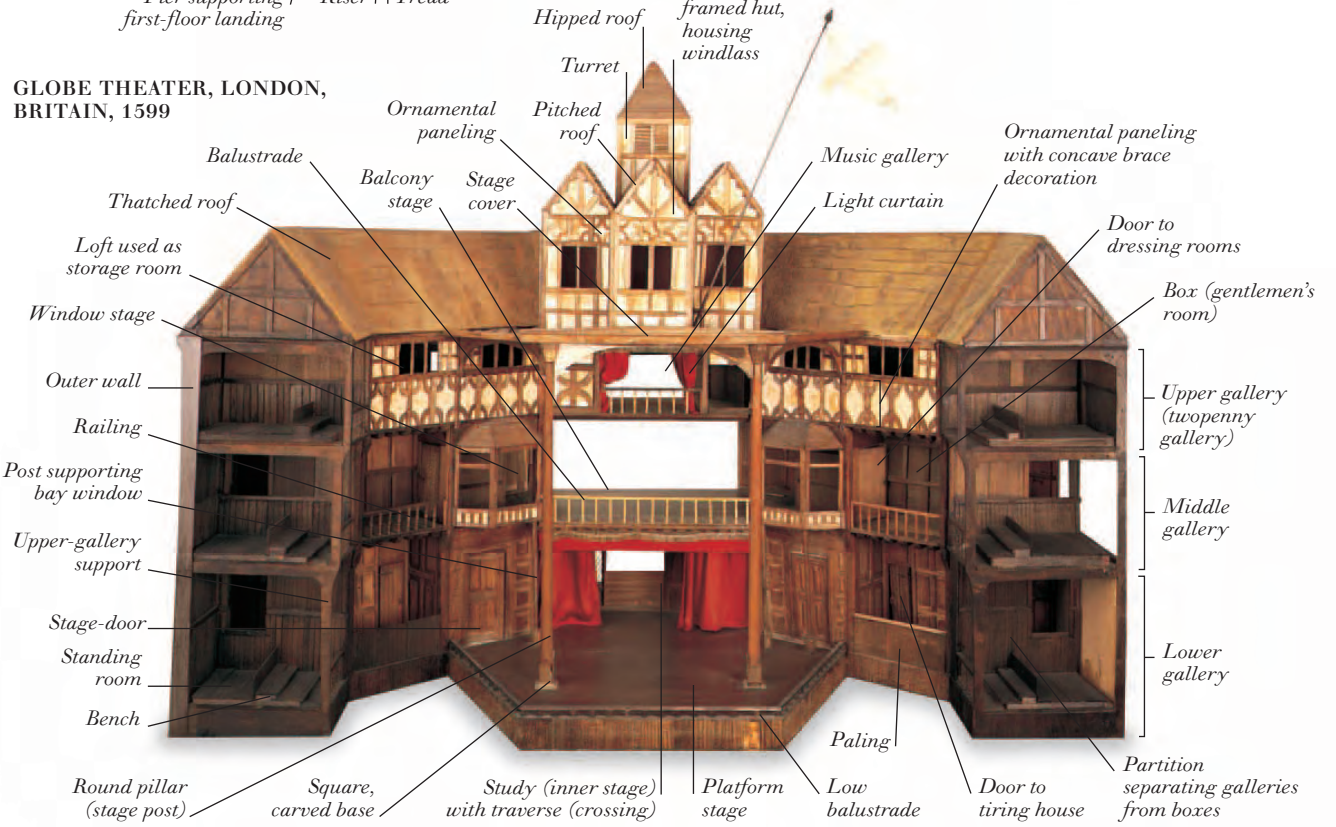
NORTH-WING STAIRCASE, CHATEAU DE MONTAL



CAMPANILE, CHURCH OF ST. EUSTACHE, PARIS, FRANCE, 1532-1640



GLOBE THEATER, LONDON, BRITAIN, 1599



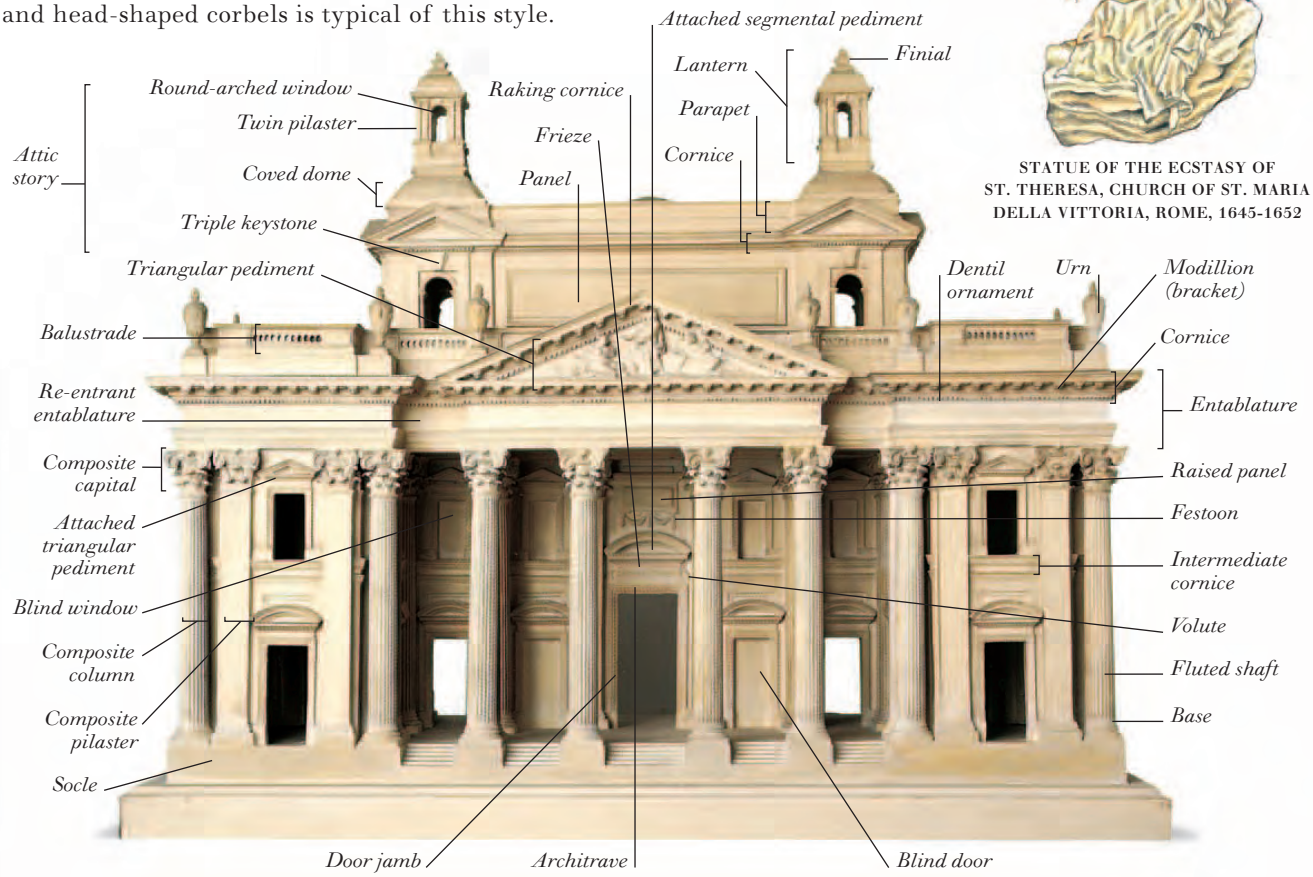
Baroque and neoclassical 1

THE BAROQUE STYLE EVOLVED IN THE EARLY 17TH CENTURY in Rome. It is characterized by curved outlines and ostentatious decoration, as can be seen in the Italian church details (right). The baroque style was particularly widely favored in Italy, Spain, and Germany. It was also adopted in Britain and France, but with adaptations. The British architects Sir Christopher Wren and Nicholas Hawksmoor, for example, used baroque features—such as the concave walls of St. Paul's Cathedral and the curved buttresses of the Church of St. George in the East (see pp. 480-481)—but they did so with restraint. Similarly, the curved buttresses and volutes of the Parisian Church of St. Paul-St. Louis are relatively plain. In the second half of the 17th century, a distinct classical style (known as neoclassicism) developed in northern Europe as a reaction to the excesses of baroque. Typical of this new style were churches such as the Madeleine (a proposed facade is shown below), as well as secular buildings such as the Cirque Napoleon (opposite) and the buildings of the British architect Sir John Soane (see pp. 482-483). In early 18th-century France, an extremely lavish form of baroque developed, known as rococo. The balcony from Nantes (see pp. 482-483) with its twisted ironwork and head-shaped corbels is typical of this style.

DETAILS FROM ITALIAN BAROQUE CHURCHES

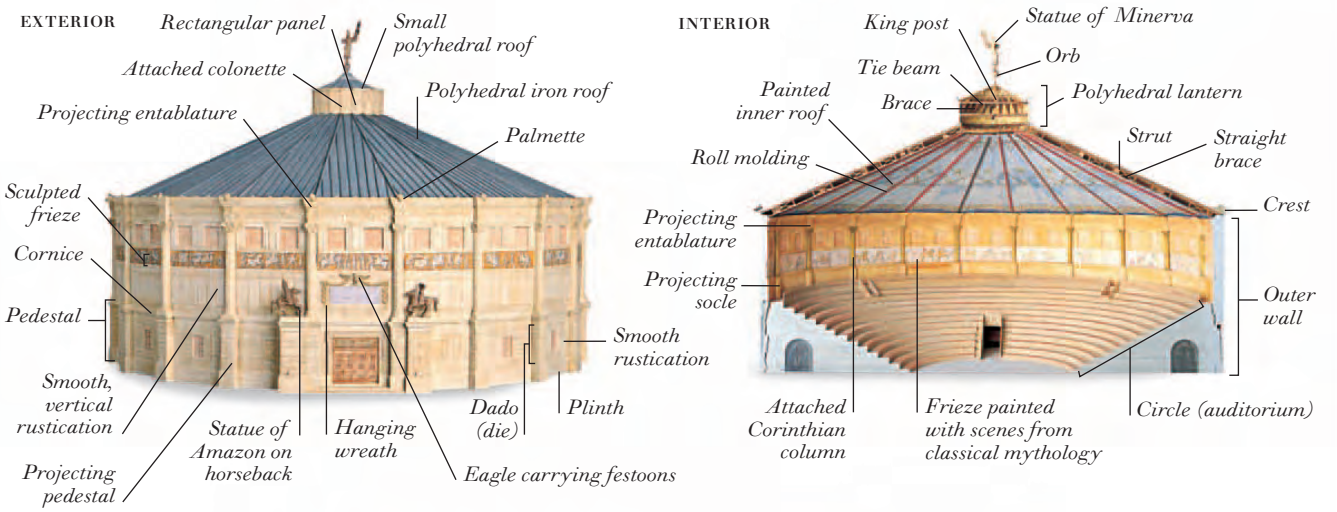
SCROLLED BUTTRESS, CHURCH OF ST. MARIA DELLA SALUTE, VENICE, 1631-1682

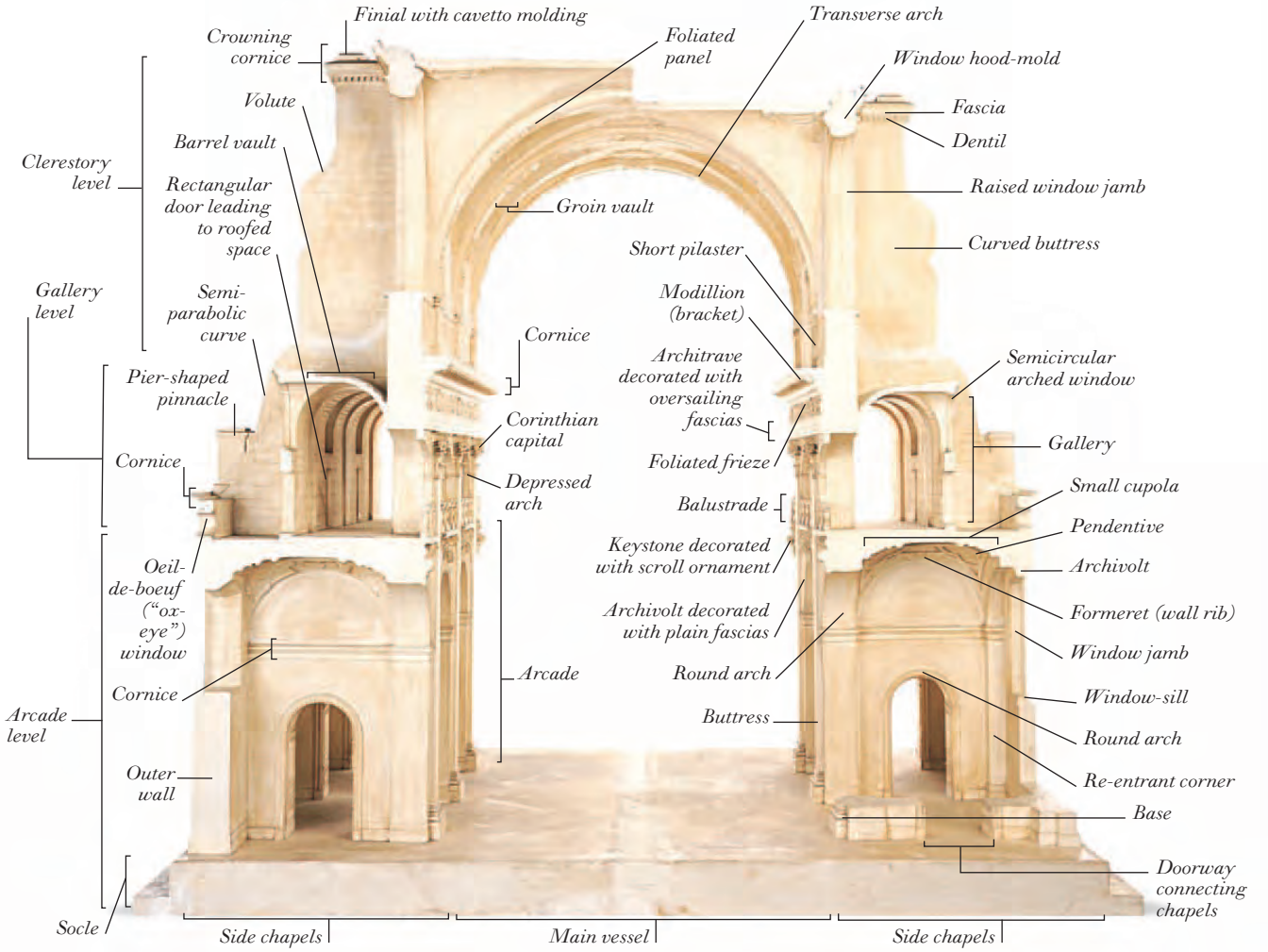
STATUE OF THE ECSTASY OF ST. THERESA, CHURCH OF ST. MARIA DELLA VITTORIA, ROME, 1645-1652



PROPOSED FACADE, THE MADELEINE (NEOCLASSICAL), PARIS, FRANCE, 1764 (BY P. CONTANT D'IVRY)

CIRQUE NAPOLEON (NEOCLASSICAL), PARIS, FRANCE, 1852 (BY J. I. HITTORFF)

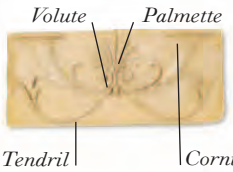




NAVE, CHURCH OF ST. PAUL-ST. LOUIS (FRENCH BAROQUE), PARIS, FRANCE, FROM 1627 (BY E. MARTELLANGE)

Baroque and neoclassical 2

ARABESQUE



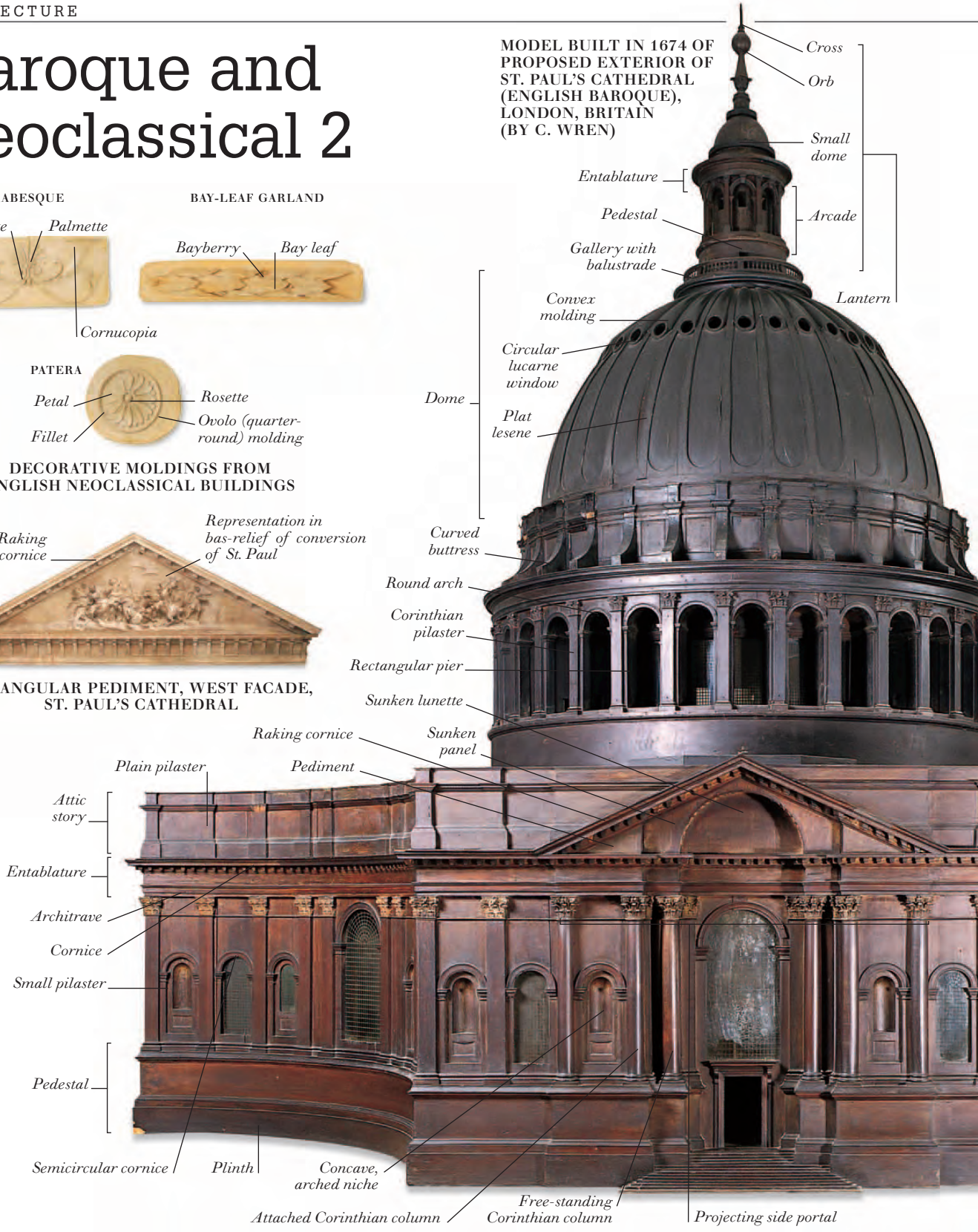
BAY-LEAF GARLAND

PATERA

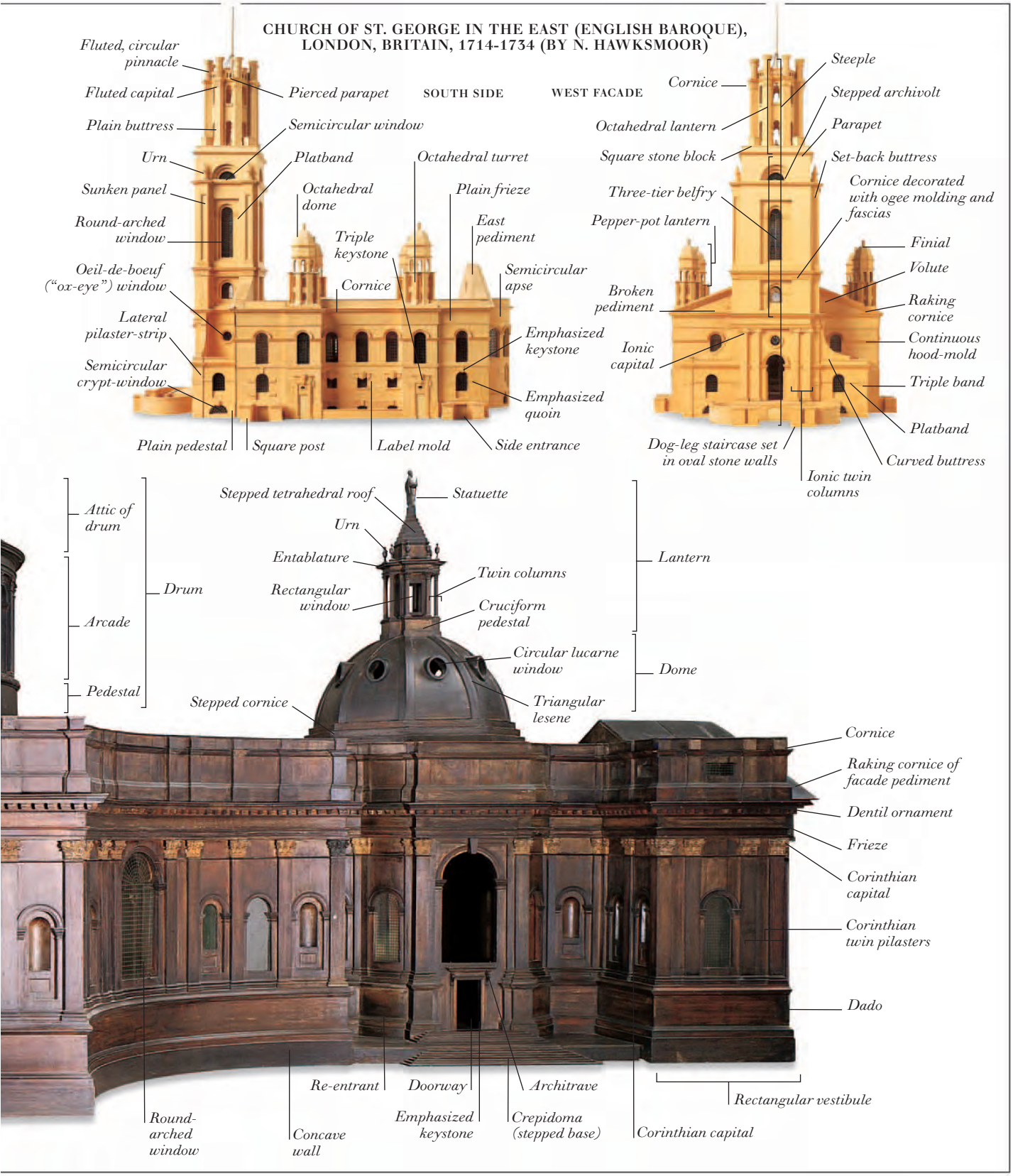
DECORATIVE MOLDINGS FROM ENGLISH NEOCLASSICAL BUILDINGS

TRIANGULAR PEDIMENT, WEST FACADE, ST. PAUL'S CATHEDRAL

MODEL BUILT IN 1674 OF PROPOSED EXTERIOR OF ST. PAUL'S CATHEDRAL (ENGLISH BAROQUE), LONDON, BRITAIN (BY C. WREN)



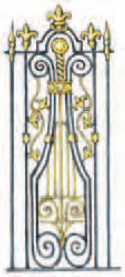
CHURCH OF ST. GEORGE IN THE EAST (ENGLISH BAROQUE), LONDON, BRITAIN, 1714-1734 (BY N. HAWKSMOOR)



Baroque and neoclassical 3

DETAILS FROM BAROQUE, NEOCLASSICAL, AND ROCOCO BUILDINGS

PORTICO, THE VYNE, HAMPSHIRE, BRITAIN, 1654 (NEOCLASSICAL)



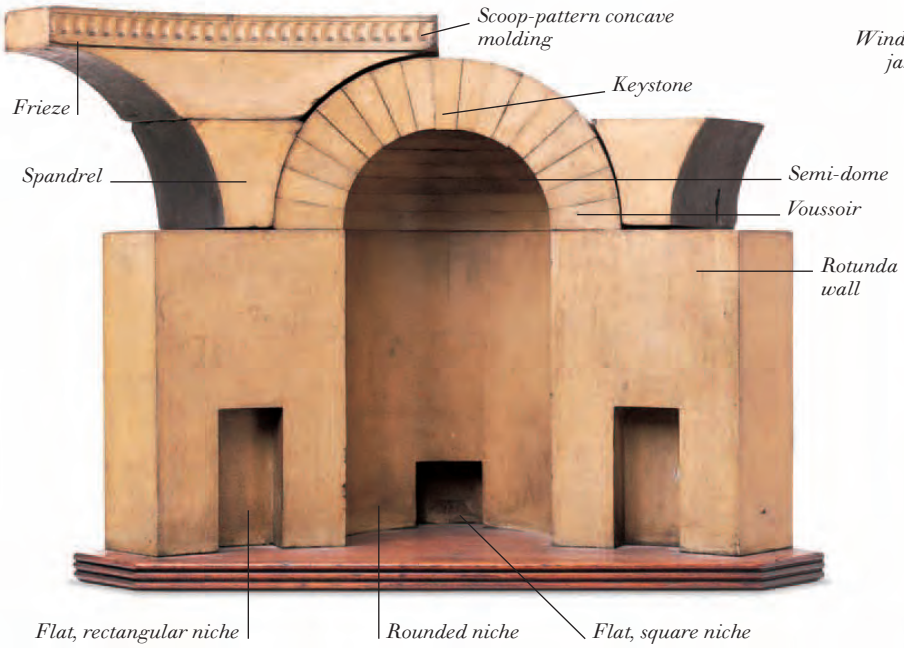
GILT IRONWORK FROM SCREEN, PALAIS DE VERSAILLES, FRANCE, 1669-1674 (FRENCH BAROQUE)

WINDOW, PALAZZO STANGA, CREMONA, ITALY, EARLY 18TH CENTURY (ROCOCO)

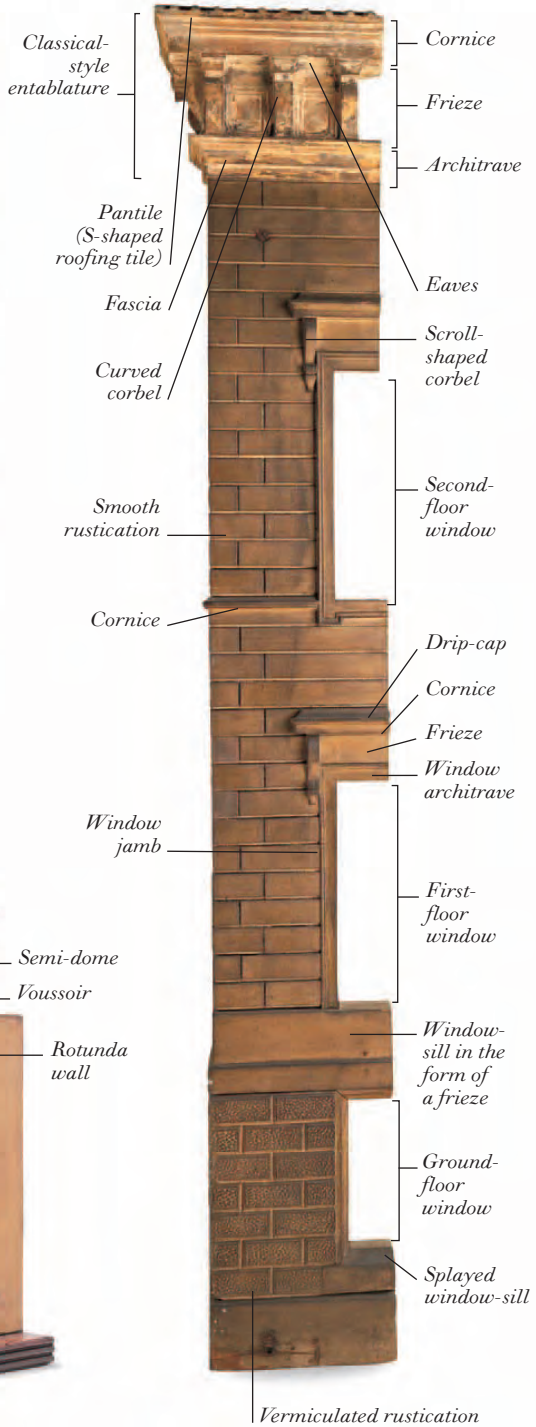
ATLAS (MALE CARYATID), UPPER BELVEDERE, VIENNA, AUSTRIA, 1721 (GERMAN-STYLE BAROQUE)

BALCONY, NANTES, FRANCE, 1730-1740 (ROCOCO)

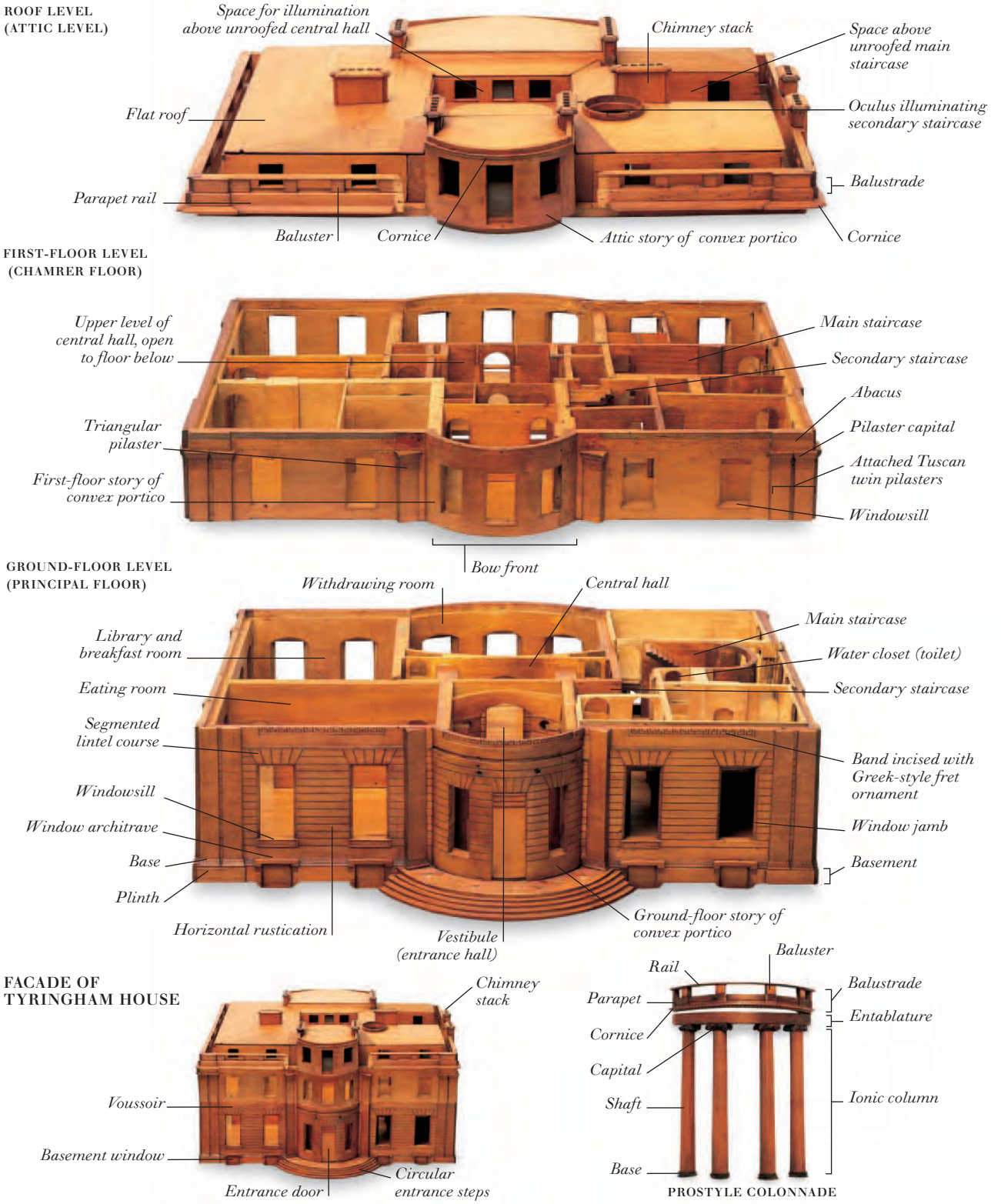
MASONRY OF A NICHE IN THE ROTUNDA (NEOCLASSICAL), BANK OF ENGLAND, LONDON, BRITAIN, 1794 (BY J. SOANE)



CORNER OF THE NEW STATE PAPER OFFICE (NEOCLASSICAL), LONDON, BRITAIN, 1830-1831 (BY J. SOANE)



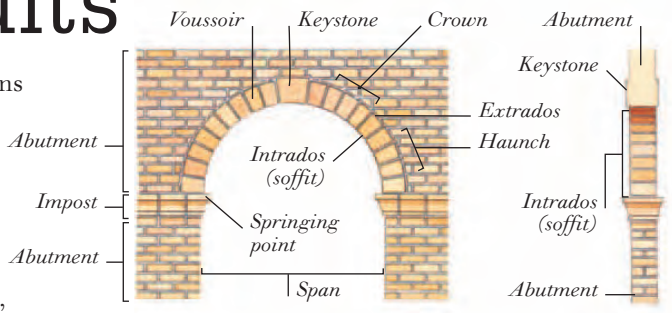
TYRINGHAM HOUSE (NEOCLASSICAL), BUCKINGHAMSHIRE, BRITAIN, 1793-1797 (BY J. SOANE)



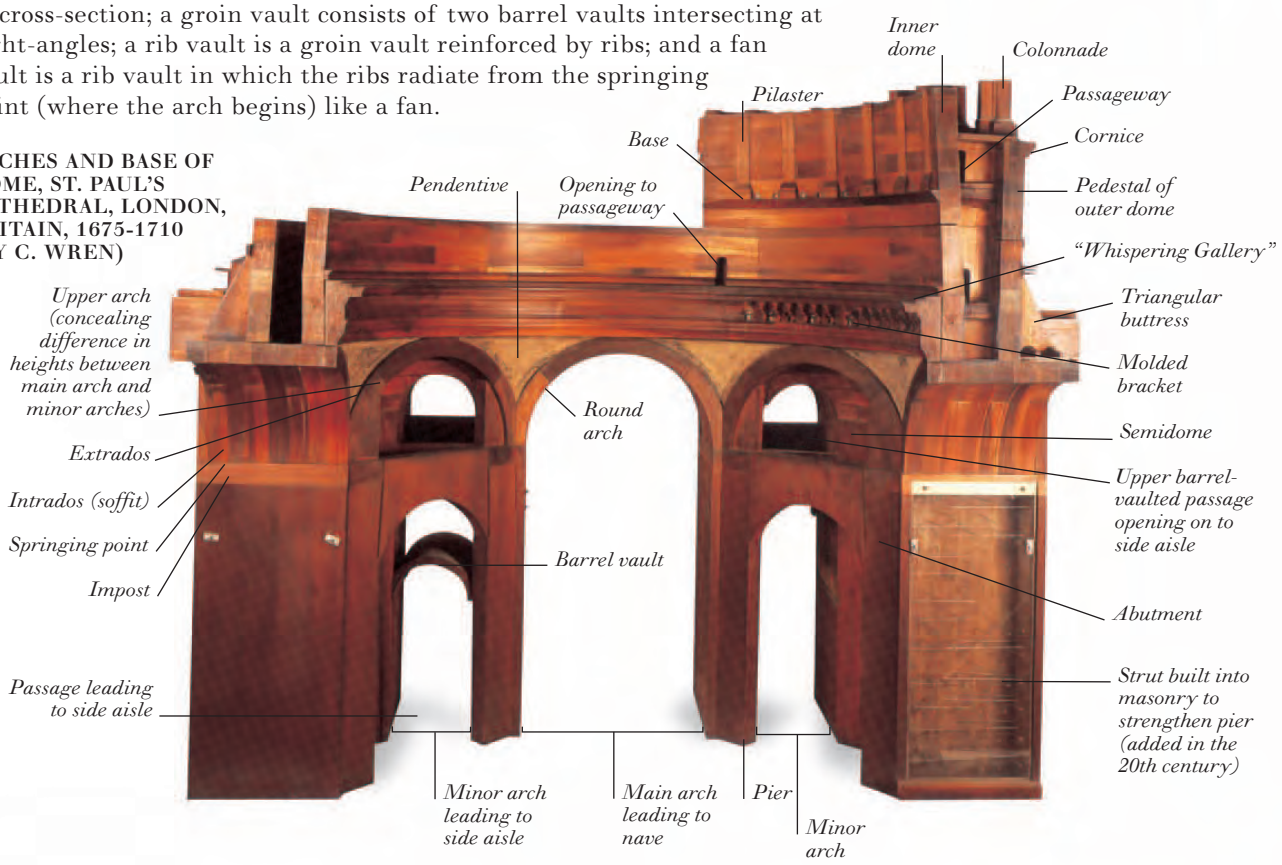
Arches and vaults

ARCHES ARE CURVED STRUCTURES used to bridge spans and to support the weight of upper parts of buildings, such as domes, as in St. Paul's Cathedral (below) and the antique temple (opposite). The voussoirs (wedge-shaped blocks) that form an arch (right) support each other and convert the downward force of the weight of the building into an outward force. This outward force is in turn transferred to buttresses, piers, or abutments. A vault is an arched roof or ceiling. There are four main types of vault (opposite). A barrel vault is a single vault, semicircular in cross-section; a groin vault consists of two barrel vaults intersecting at right-angles; a rib vault is a groin vault reinforced by ribs; and a fan vault is a rib vault in which the ribs radiate from the springing point (where the arch begins) like a fan.

PARTS OF AN ARCH



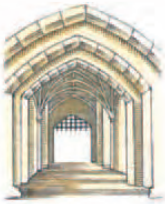
ARCHES AND BASE OF DOME, ST. PAUL'S CATHEDRAL, LONDON, BRITAIN, 1675-1710 (BY C. WREN)



TYPES OF ARCH

HORSESHOE ARCH (MOORISH ARCH), GREAT MOSQUE, CORDORA, SPAIN, 785

BASKET ARCH (SEMI-ELLIPTICAL ARCH), PALATINE CHAPEL, AIX-LA-CHAPELLE, FRANCE, 790-798

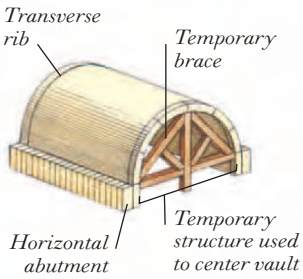


TUDOR ARCH, TOWER OF LONDON, BRITAIN, c.1086-1097

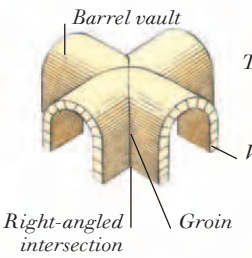
LANCET ARCH, WESTMINSTER ABBEY, LONDON, BRITAIN, 1503-1519

TREFOIL ARCH, BEVERLEY MINSTER, YORKSHIRE, BRITAIN, c.1300

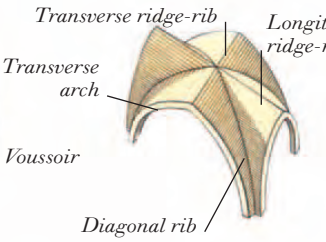
TYPES OF VAULT



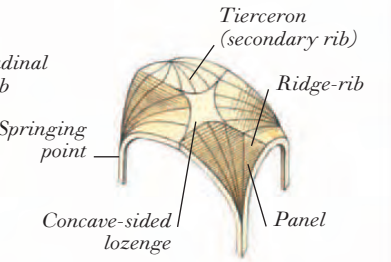
BARREL VAULT (TUNNEL VAULT; WAGON VAULT)



GROIN VAULT

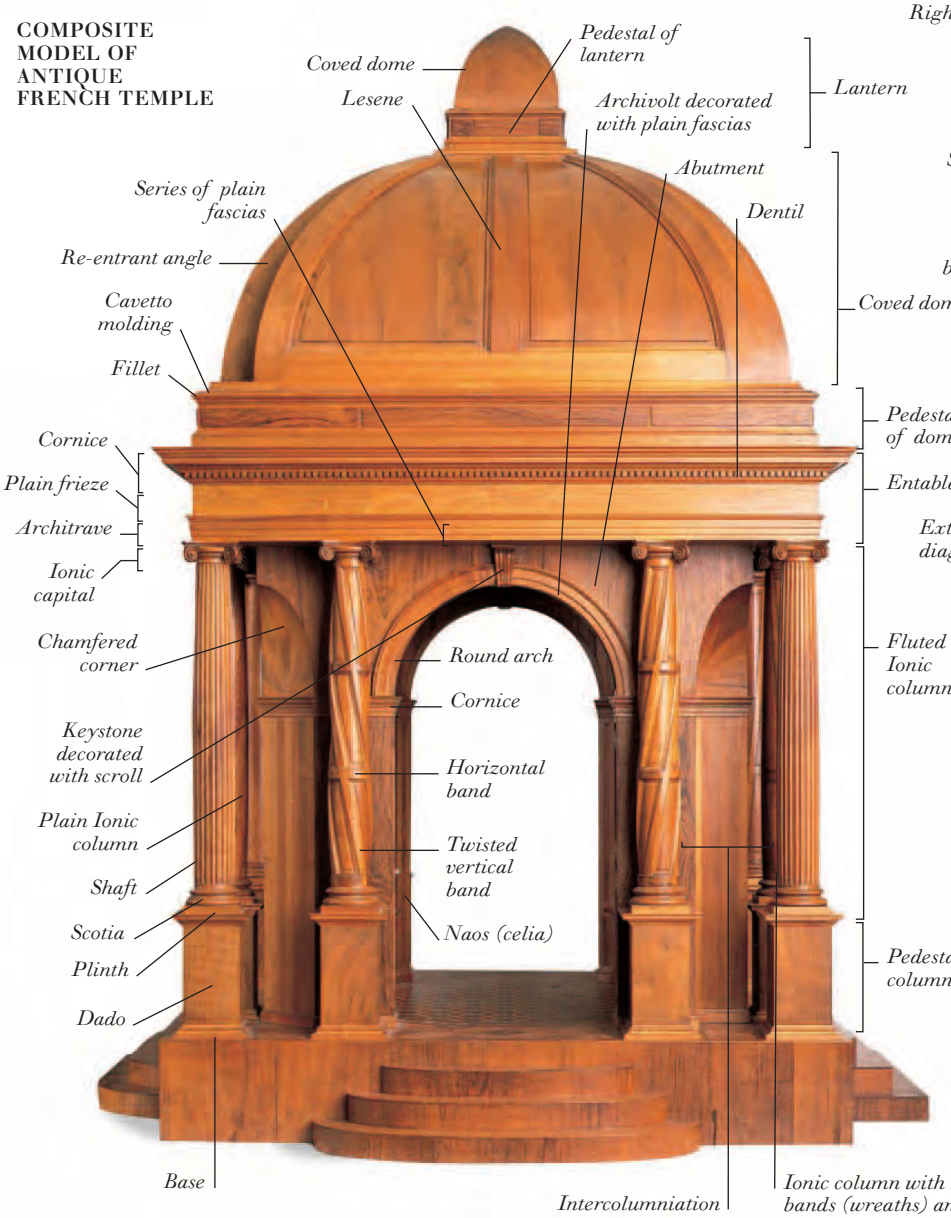


RIB VAULT

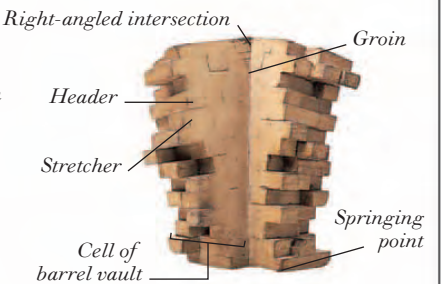


FAN VAULT

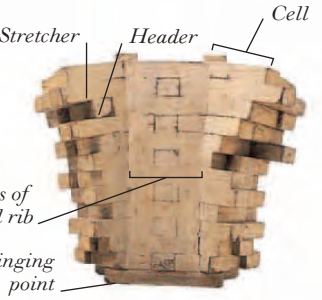
COMPOSITE MODEL OF ANTIQUE FRENCH TEMPLE



ENGLISH BOND BRICKWORK OF GROIN VAULT AND RIB VAULT

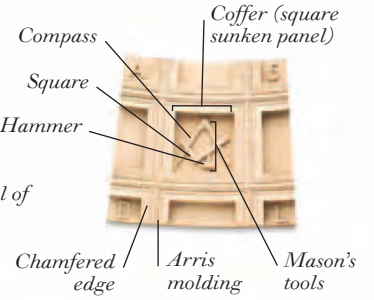


EXTRADOS OF GROIN VAULT



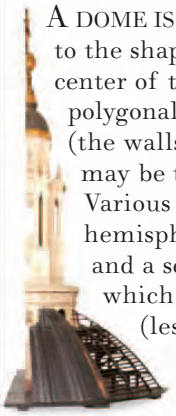
EXTRADOS OF RIB VAULT

INTERIOR DECORATION OF COFFERED VAULT



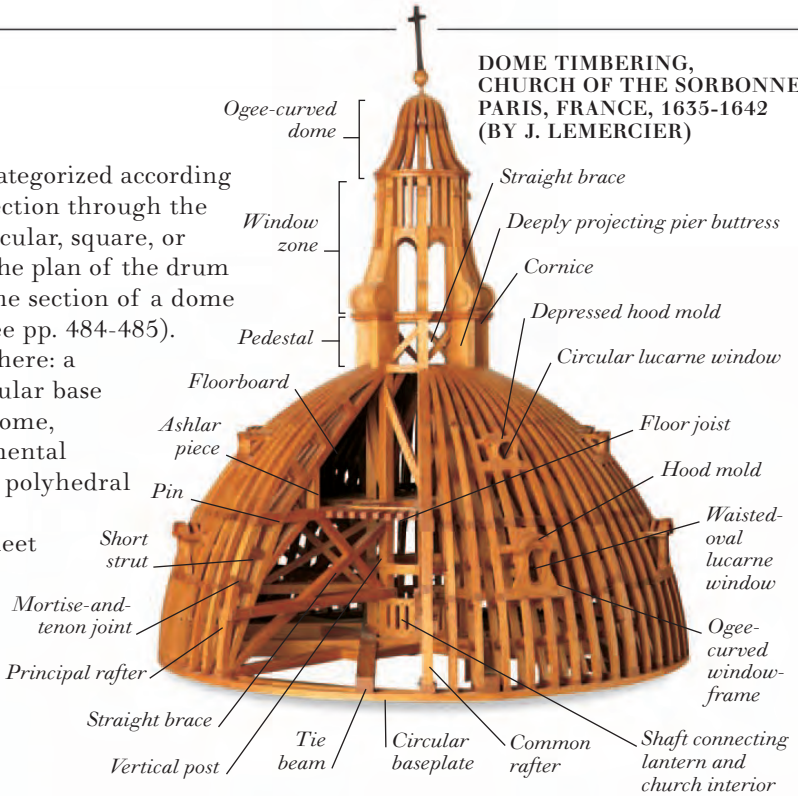
Domes

A DOME IS A CONVEX ROOF. Domes are categorized according to the shapes of both the base and the section through the center of the dome. The base may be circular, square, or polygonal (many-sided), depending on the plan of the drum (the walls on which the dome rests). The section of a dome may be the same shape as any arch (see pp. 484-485). Various types of dome are illustrated here: a hemispherical dome, which has a circular base and a semicircular section; a saucer dome, which has a circular base and a segmental (less than a semicircle) section; a polyhedral dome, which is a dome on a polygonal base whose sides meet at the top of the dome; and an onion dome, which has a circular or polygonal base and an ogee-shaped section. Many domes have a lantern (a turret with windows) to provide light inside.

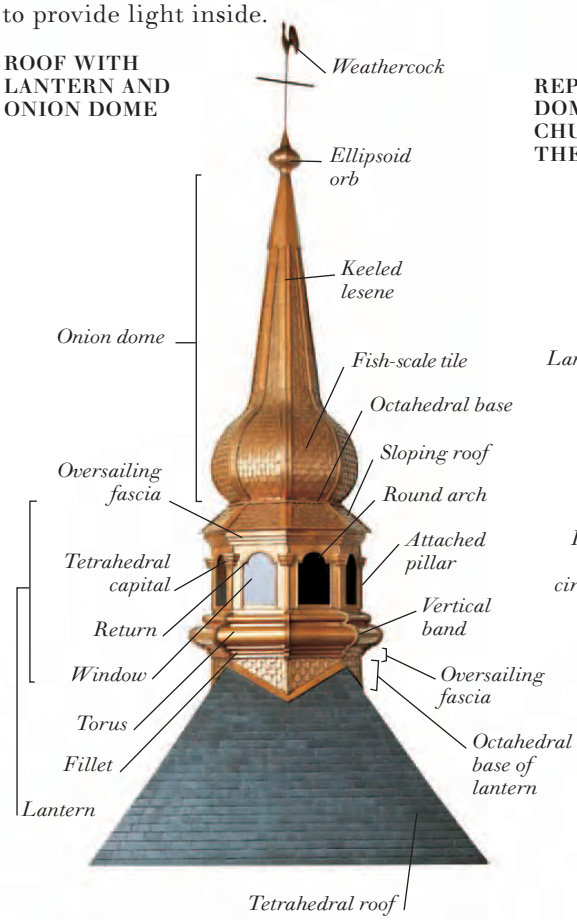


LANTERN AND UPPER DOME TIMBERING, ST. PAUL'S CATHEDRAL

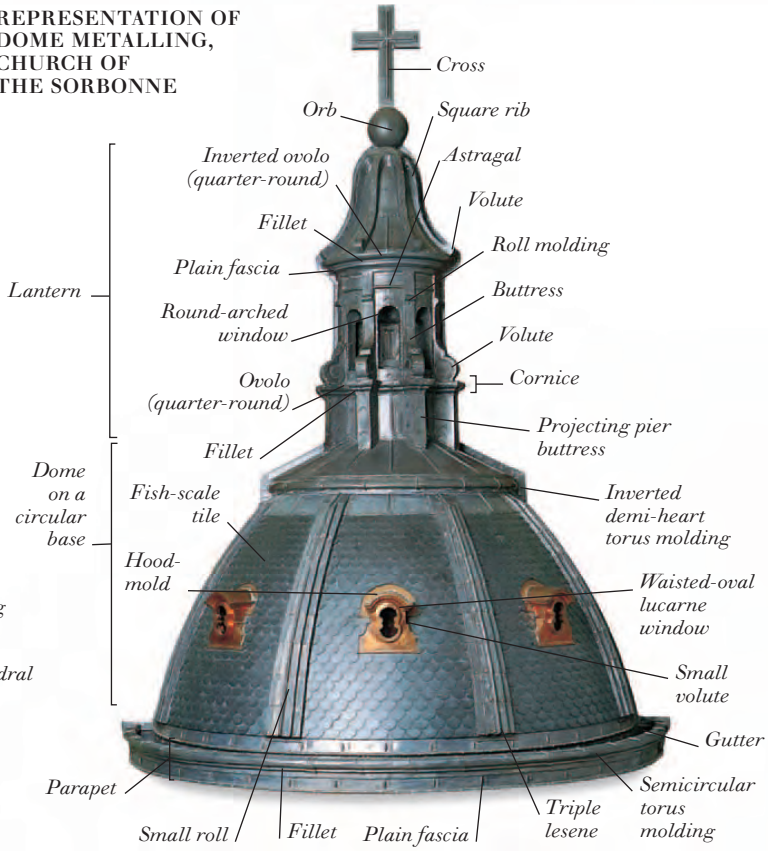
DOME TIMBERING, CHURCH OF THE SORBONNE, PARIS, FRANCE, 1635-1642 (BY J. LEMERCIER)



ROOF WITH LANTERN AND ONION DOME



REPRESENTATION OF DOME METALLING, CHURCH OF THE SORBONNE



TYPES OF DOME

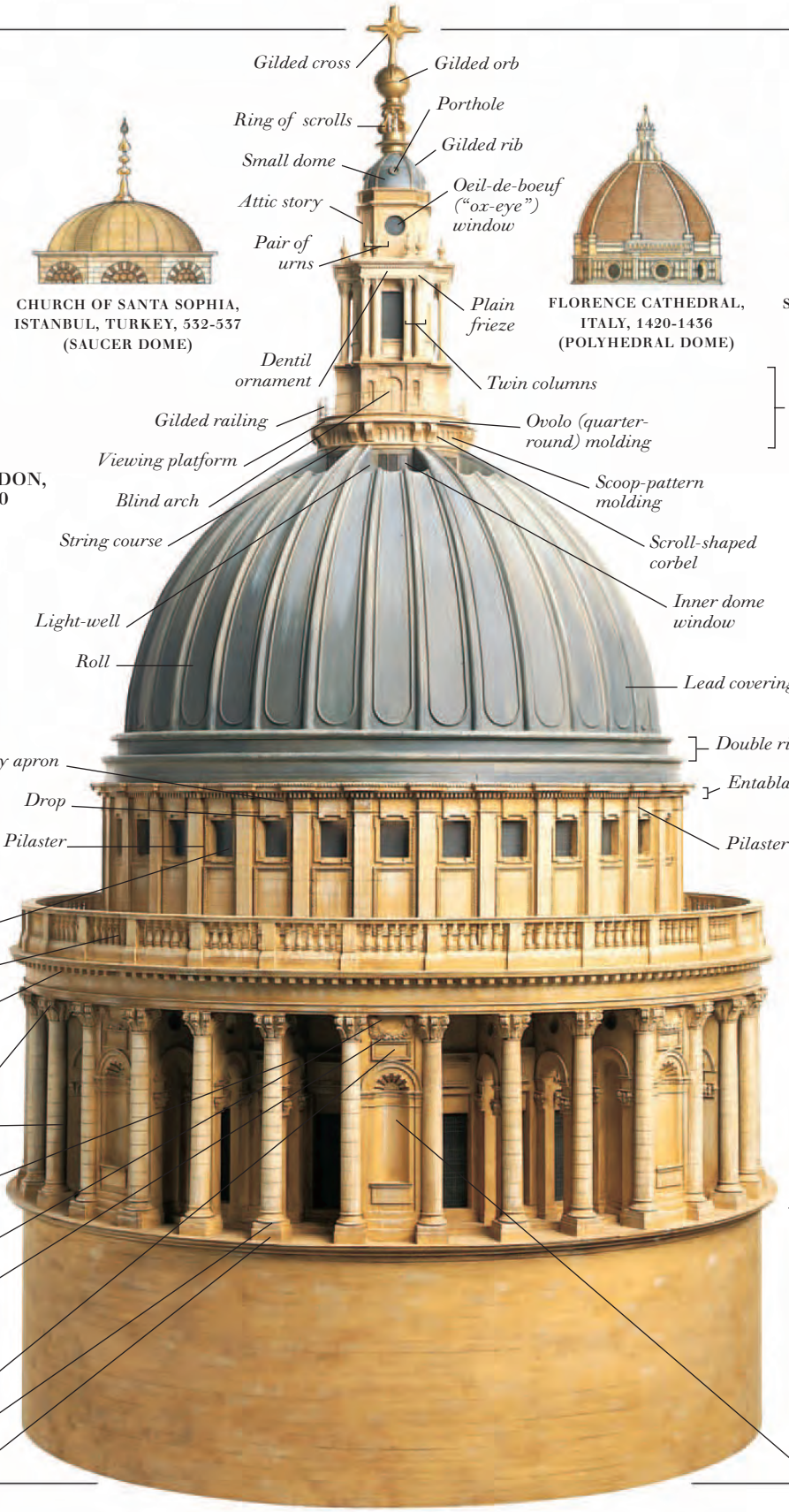
DOME OF THE ROCK, JERUSALEM, ISRAEL, FROM C.684 (HEMISPHERICAL DOME)

CHURCH OF SANTA SOPHIA, ISTANBUL, TURKEY, 532-537 (SAUCER DOME)

FLORENCE CATHEDRAL, ITALY, 1420-1436 (POLYHEDRAL DOME)

ST. BASIL'S CATHEDRAL, MOSCOW, RUSSIA, 1555-1561 (ONION DOME)

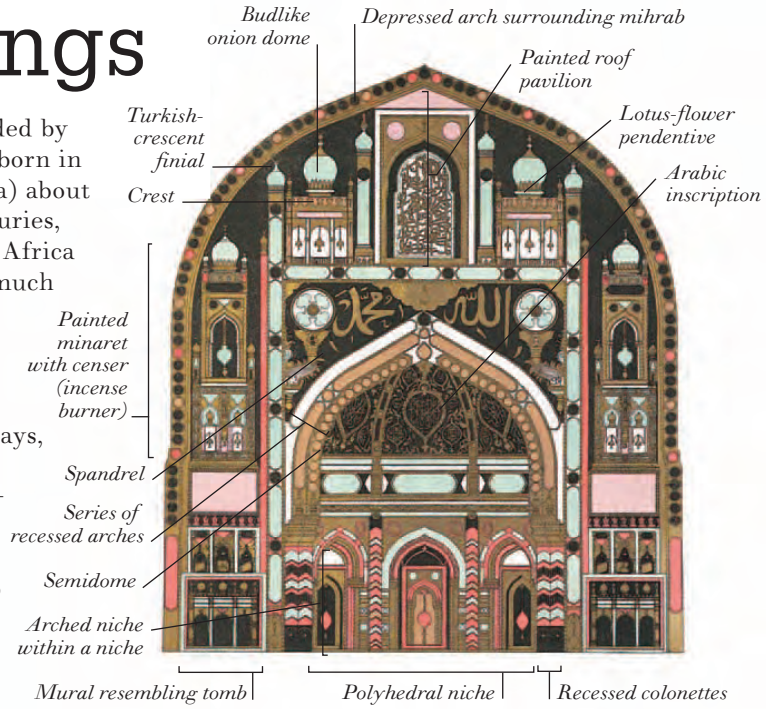
DOME, ST. PAUL'S CATHEDRAL, LONDON, BRITAIN, 1675-1710 (BY C. WREN)



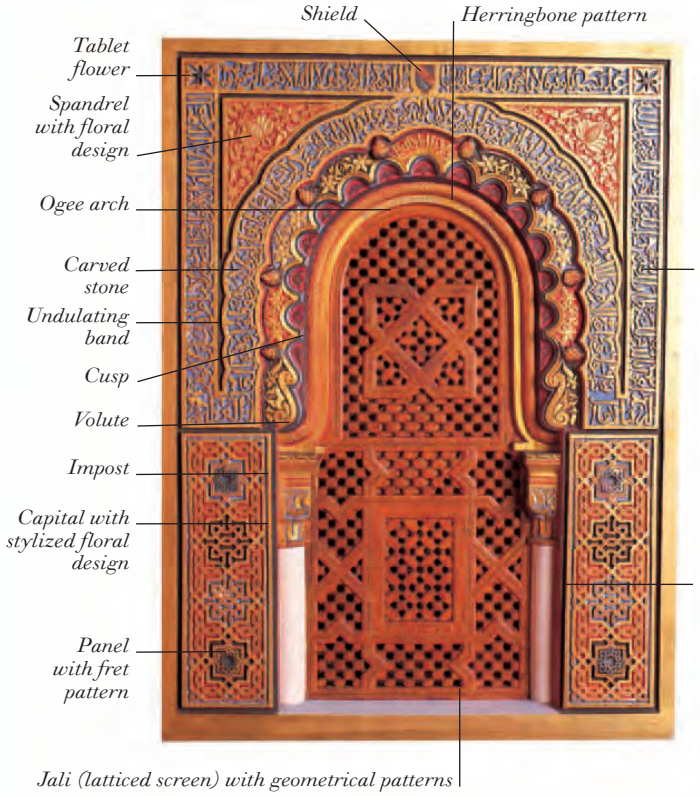
Islamic buildings

OPUS SECTILE MOSAIC DESIGN

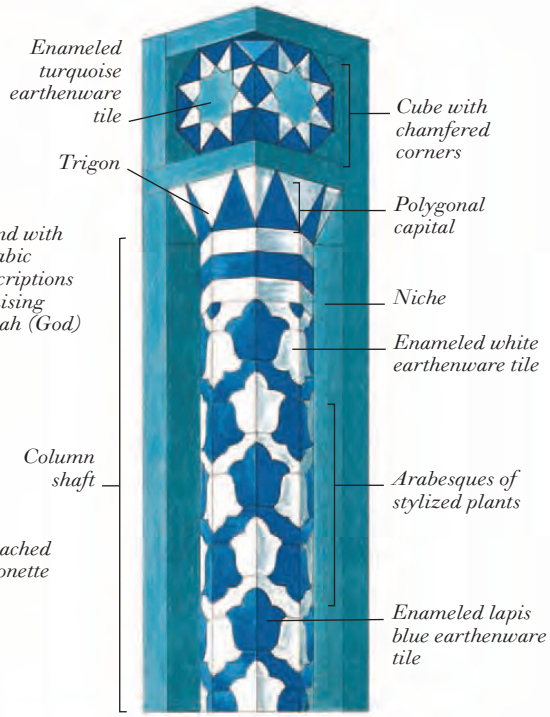
THE ISLAMIC RELIGION was founded by the prophet Mohammed, who was born in Mecca (in present-day Saudi Arabia) about 570 AD. In the following three centuries, Islam spread from Arabia to North Africa and Spain, as well as to India and much of the rest of Asia. The worldwide influence of Islam remains strong today. Common characteristics of Islamic buildings include ogee arches and roofs, onion domes, and walls decorated with carved stone, paintings, inlays, or mosaics. The most important type of Islamic building is the mosque—the place of worship—which generally has a minaret (tower) from which the muezzin (official crier) calls Muslims to prayer. Most mosques have a mihrab (decorative niche) that indicates the direction of Mecca. As figurative art is not allowed in Islam, buildings are ornamented with geometric and arabesque motifs, and inscriptions (frequently Koranic verses).



MIHRAB, JAMI MASJID (PRINCIPAL OR CONGREGATIONAL MOSQUE), BIJAPUR, INDIA, c.1636

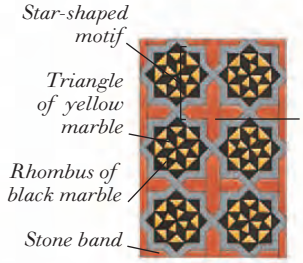


ARCH, THE ALHAMBRA, GRANADA, SPAIN, 1333-1354

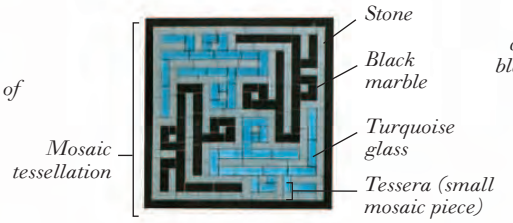


MIHRAB WITH COLUMN, EL-AINYI MOSQUE, CAIRO, EGYPT, 15TH CENTURY

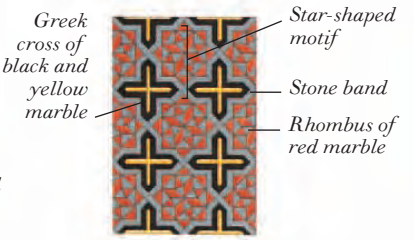
EXAMPLES OF ISLAMIC MOSAICS, EGYPT AND SYRIA



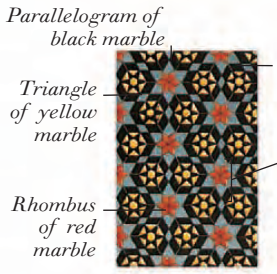
STAR AND GREEK-CROSS MOSAIC



FRET-PATTERN MOSAIC



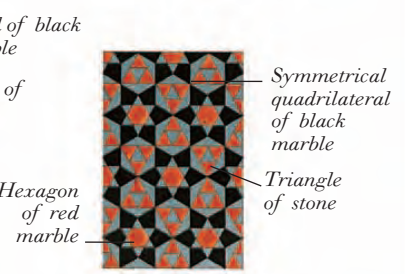
STAR AND GREEK-CROSS MOSAIC



MOSAIC OF HEXAGONS, TRIANGLES, AND SYMMETRICAL QUADRILATERALS

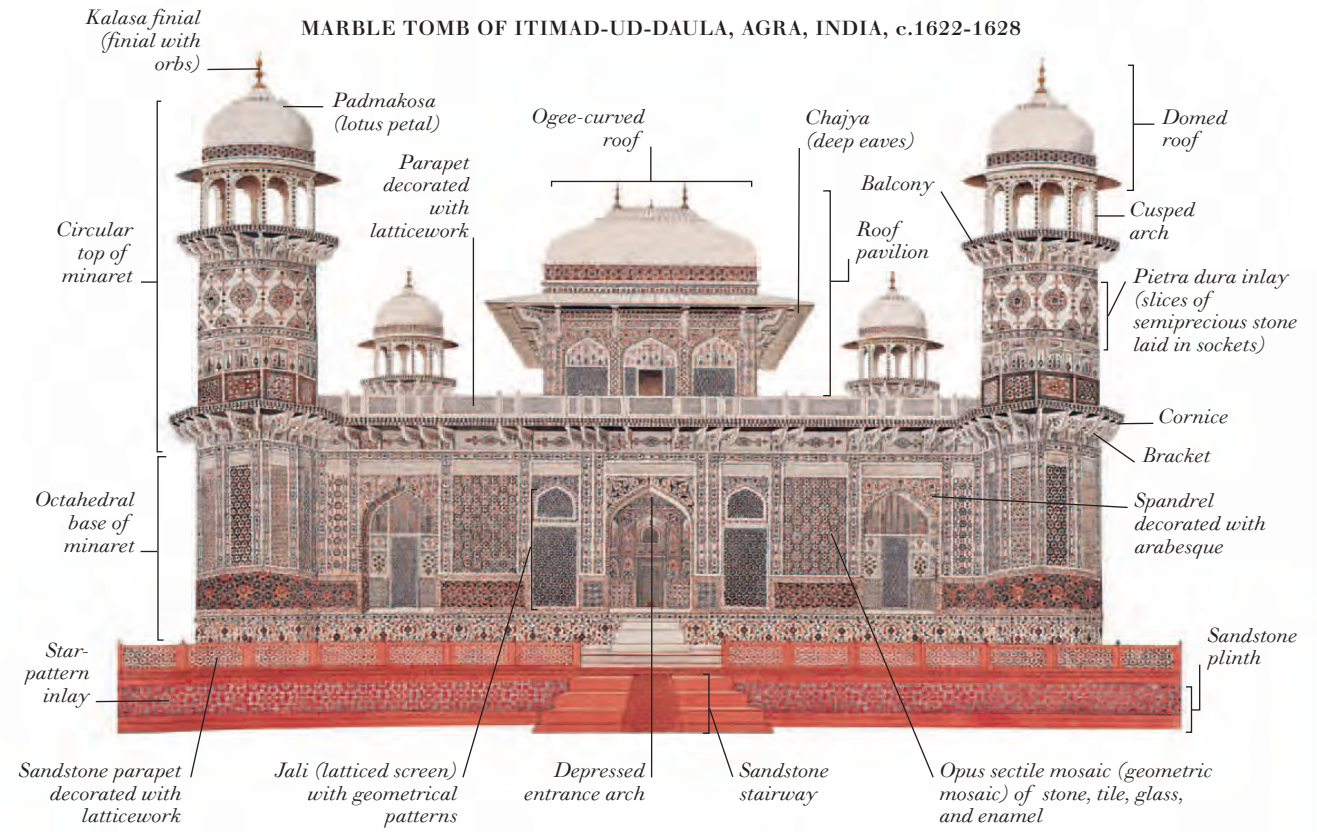
HEXAGON AND BAND MOSAIC

DANCETTE-PATTERN MOSAIC



MOSAIC OF HEXAGONS, TRIANGLES, AND SYMMETRICAL QUADRILATERALS

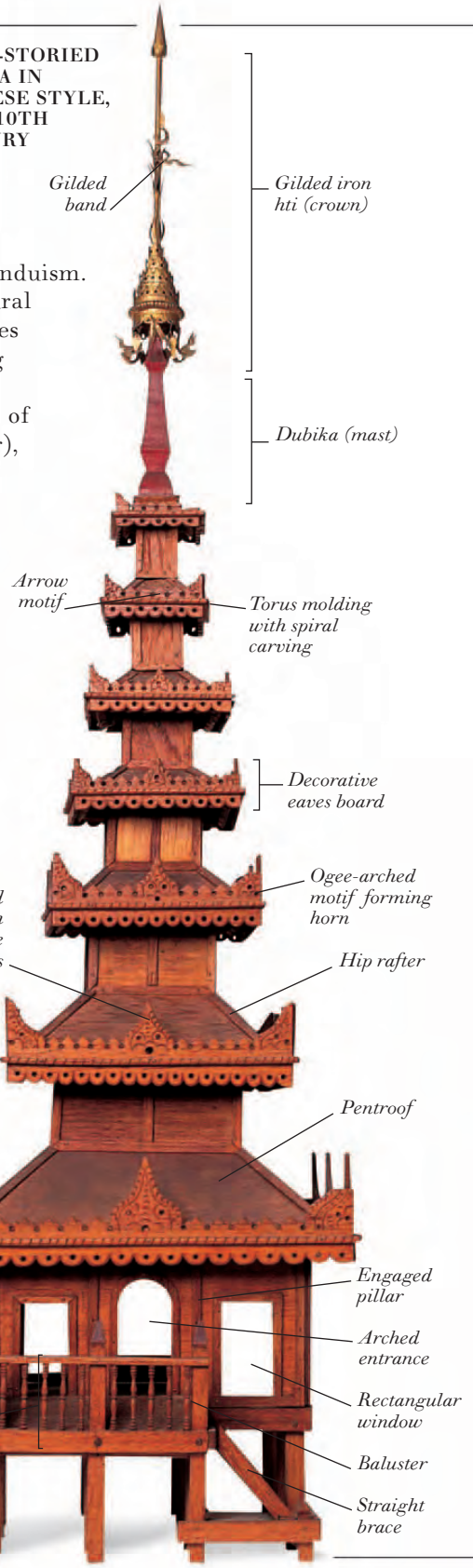
MARBLE TOMB OF ITIMAD-UD-DAULA, AGRA, INDIA, c.1622-1628



South and east Asia

THE TRADITIONAL ARCHITECTURE of south and east Asia has been profoundly influenced by the spread from India of Buddhism and Hinduism. This influence is shown both by the abundance and by the architectural styles of temples and shrines in the region. Many early Hindu temples consist of rooms carved from solid rock-faces. However, free-standing structures began to be built in southern India from about the eighth century AD. Many were built in the Dravidian style, like the Temple of Virupaksha (opposite) with its characteristic antarala (terraced tower), perforated windows, and numerous arches, pilasters, and carvings. The earliest Buddhist religious monuments were Indian stupas, which consisted of a single hemispherical dome surmounted by a chattravali (shaft) and surrounded by railings with ornate gates. Later Indian stupas and those built elsewhere were sometimes modified; for example, in Sri Lanka, the dome became bell-shaped, and was called a dagoba. Buddhist pagodas, such as the Burmese example (right), are multistoried temples, each story having a projecting roof. The form of these buildings probably derived from the yasti (pointed spire) of the stupa. Another feature of many traditional Asian buildings is their imaginative roof-forms, such as gambrel (mansard) roofs, and roofs with angle-rafters (below).

SEVEN-STORIED PAGODA IN BURMESE STYLE, c.9TH-10TH CENTURY



DETAILS FROM EAST ASIAN BUILDINGS

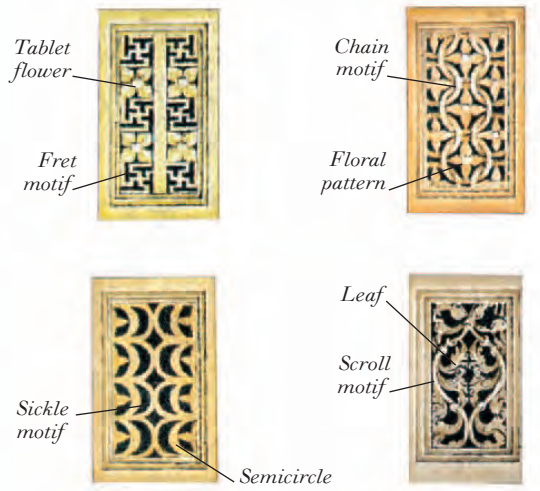
KASUGA-STYLE ROOF WITH SUMIGI (ANGLE-RAFTERS), KASUGADO SHRINE OF ENJOJI, NARA, JAPAN, 12TH-14TH CENTURY

TERRACES, TEMPLE OF HEAVEN, BEIJING, CHINA, 15TH CENTURY

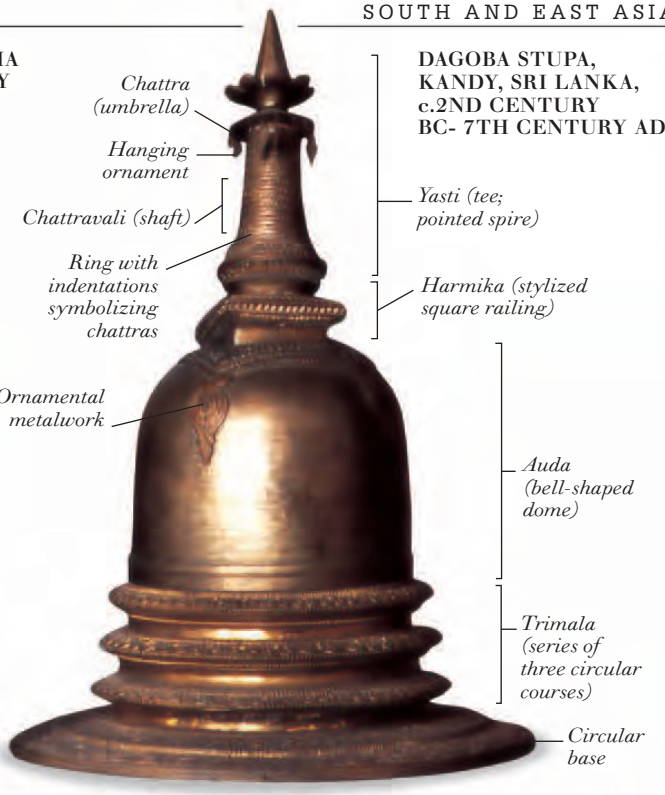
GAMBREL (MANSARD) ROOF WITH UPSWEPT EAVES AND UNDULATING GABLES, HIMEJI CASTLE, HIMEJI, JAPAN, 1608-1609

CORNER CAPITAL WITH ROOF BEAMS, POPCHU-SA TEMPLE, POPCHU-SA, SOUTH KOREA, 17TH CENTURY

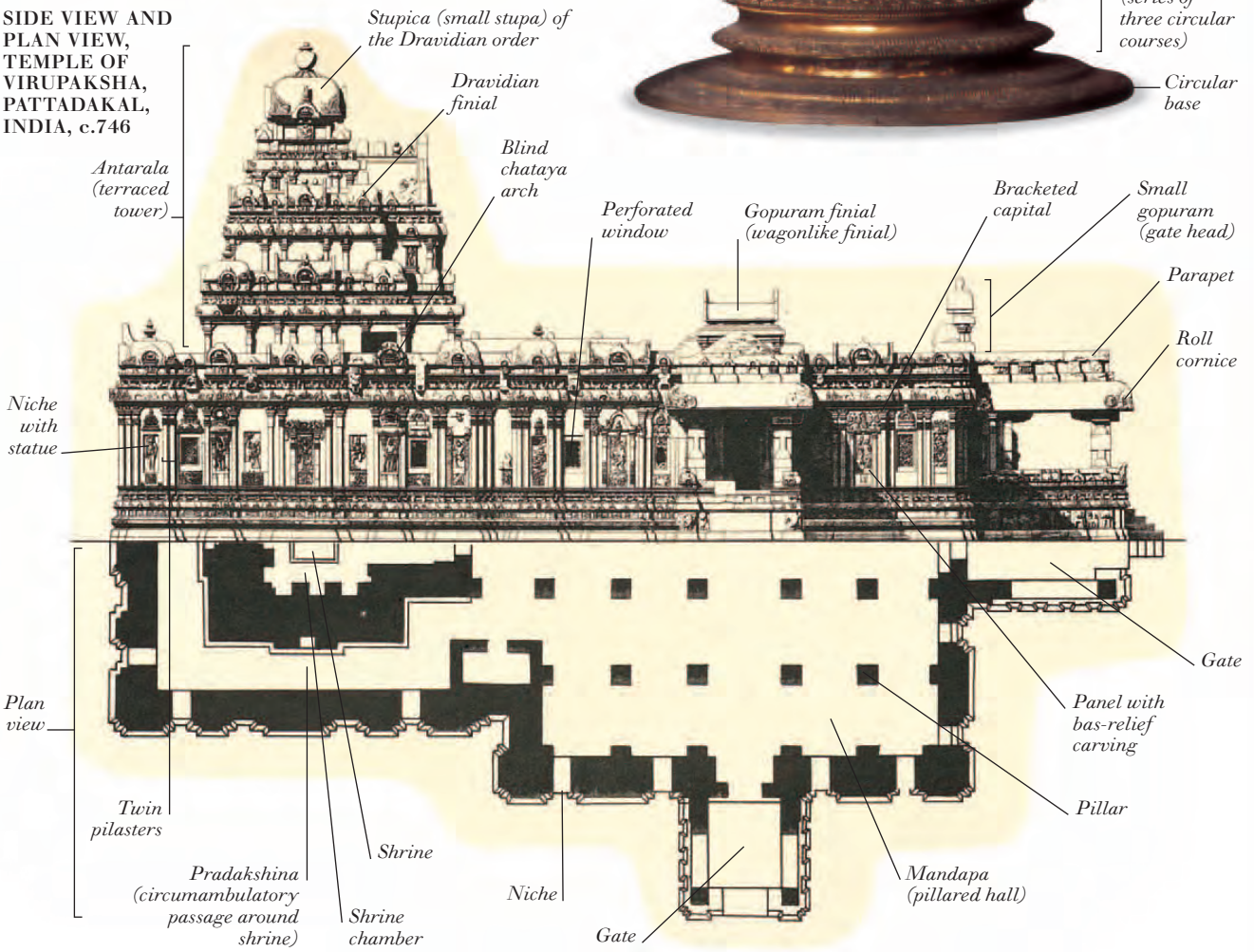
PERFORATED STONE WINDOWS, TEMPLES OF VIRUPAKSHA AND MALLIKARJUNA, PATTADAKAL, INDIA, 8TH CENTURY



DAGOBA STUPA, KANDY, SRI LANKA, c.2ND CENTURY BC- 7TH CENTURY AD



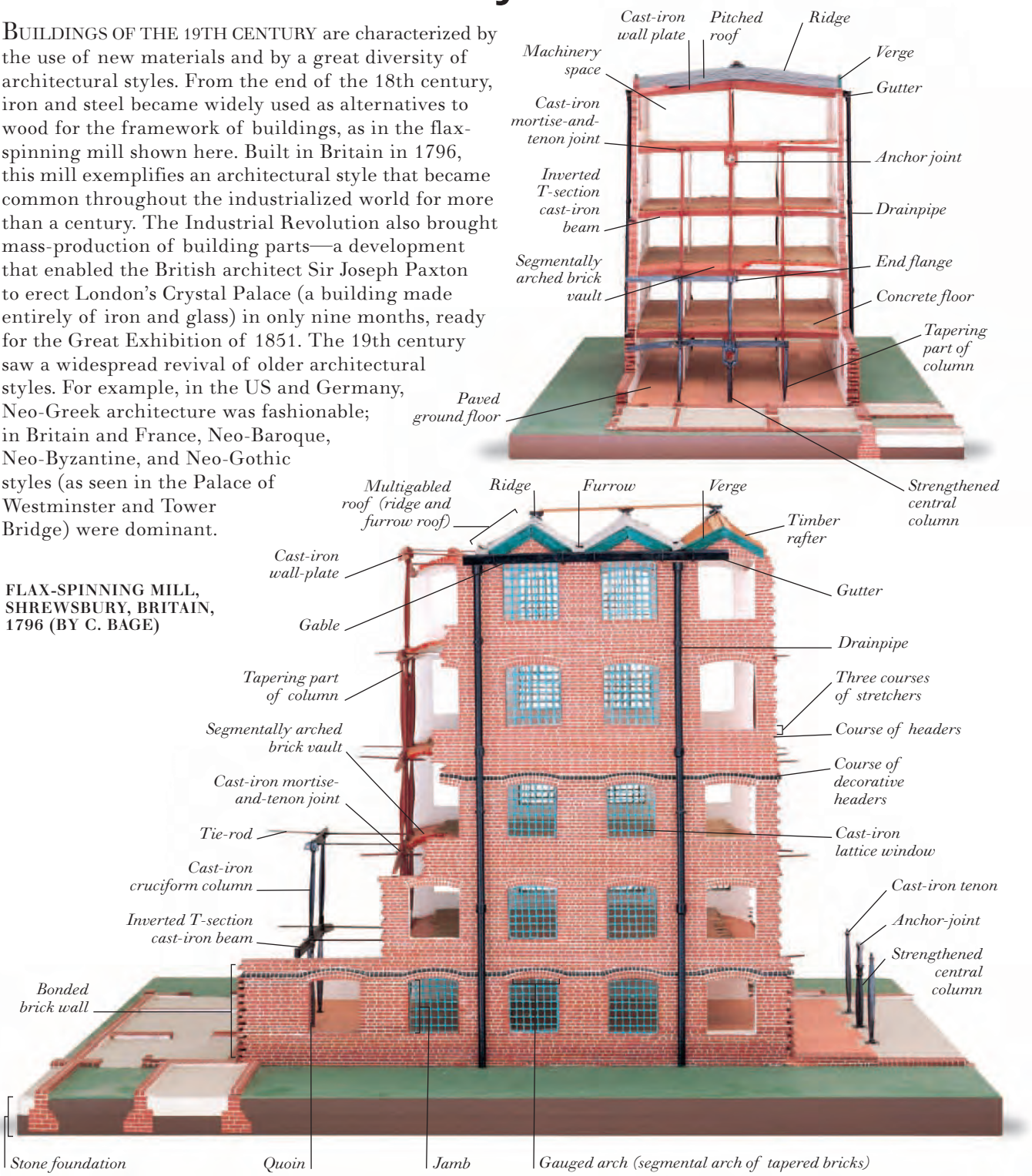
SIDE VIEW AND PLAN VIEW, TEMPLE OF VIRUPAKSHA, PATTADAKAL, INDIA, c.746



The 19th century

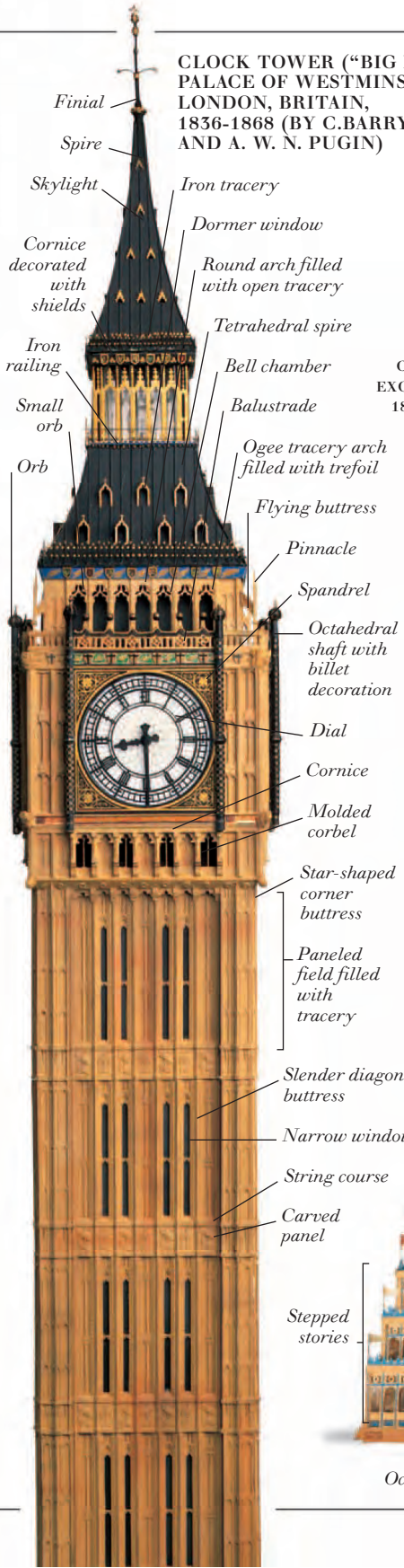
BUILDINGS OF THE 19TH CENTURY are characterized by the use of new materials and by a great diversity of architectural styles. From the end of the 18th century, iron and steel became widely used as alternatives to wood for the framework of buildings, as in the flax-spinning mill shown here. Built in Britain in 1796, this mill exemplifies an architectural style that became common throughout the industrialized world for more than a century. The Industrial Revolution also brought mass-production of building parts—a development that enabled the British architect Sir Joseph Paxton to erect London's Crystal Palace (a building made entirely of iron and glass) in only nine months, ready for the Great Exhibition of 1851. The 19th century saw a widespread revival of older architectural styles. For example, in the US and Germany, Neo-Greek architecture was fashionable; in Britain and France, Neo-Baroque, Neo-Byzantine, and Neo-Gothic styles (as seen in the Palace of Westminster and Tower Bridge) were dominant.

SECTION THROUGH A FLAX-SPINNING MILL



FLAX-SPINNING MILL, SHREWSBURY, BRITAIN, 1796 (BY C. BAGE)

CLOCK TOWER ("BIG BEN"), PALACE OF WESTMINSTER, LONDON, BRITAIN, 1836-1868 (BY C.BARRY AND A. W. N. PUGIN)

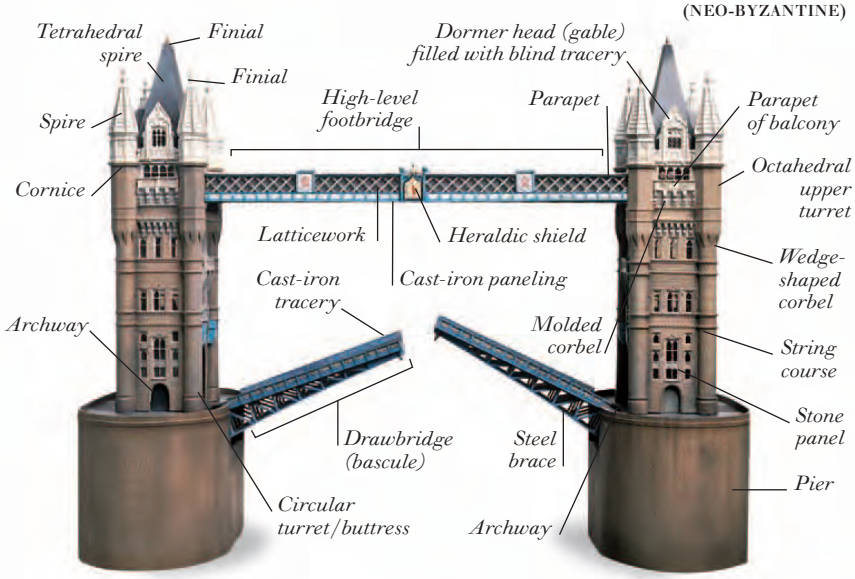


DETAILS FROM BUILDINGS IN REVIVALIST STYLES

CUPOLA, MERCHANTS' EXCHANGE, PHILADELPHIA 1832-1834 (NEO-GREEK)

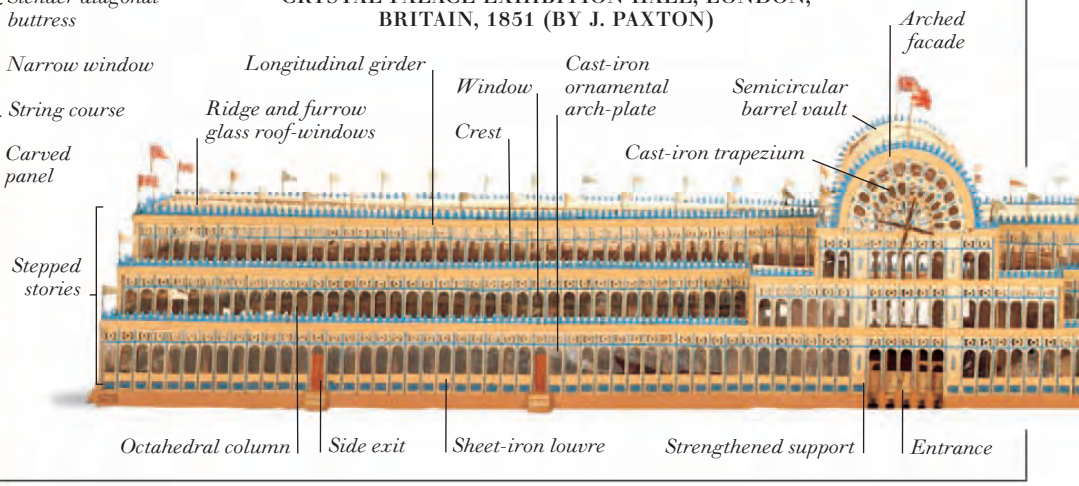
SCULPTURE AND PEDIMENT, OPERA HOUSE, PARIS, FRANCE, 1861-1874 (NEO-BAROQUE)

DOMED TURRET, WESTMINSTER CATHEDRAL, LONDON, BRITAIN, 1894-1903 (NEO-BYZANTINE)



TOWER BRIDGE, LONDON, BRITAIN, 1886-1894 (BY H. JONES)

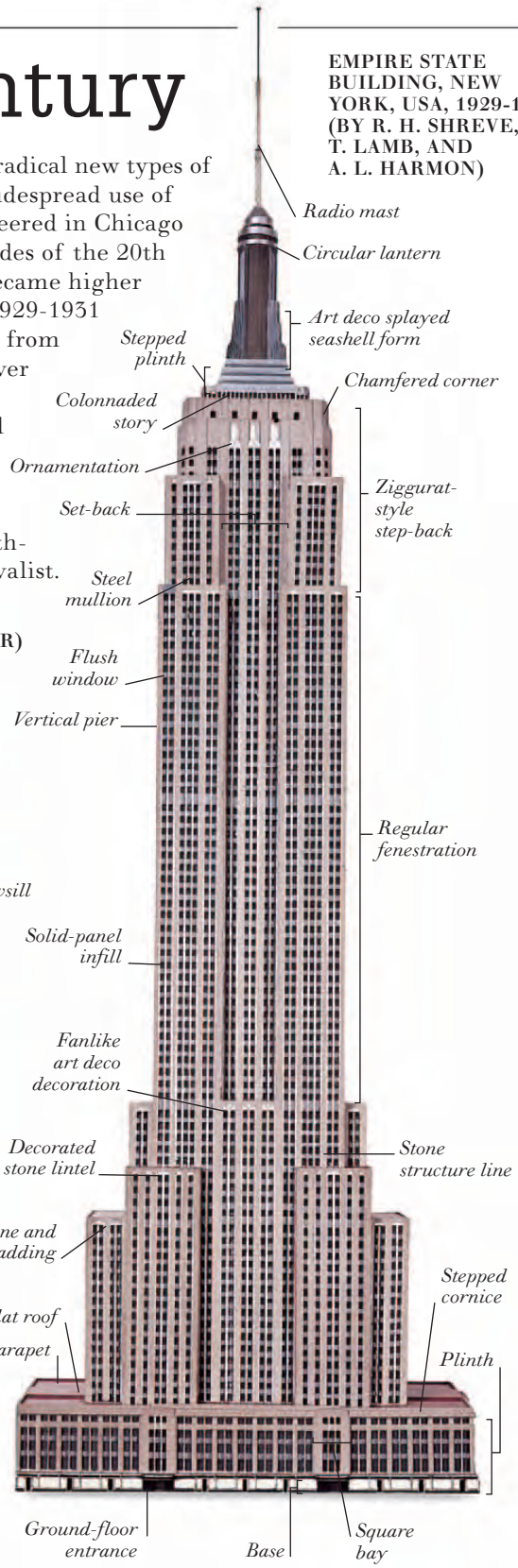
CRYSTAL PALACE EXHIBITION HALL, LONDON, BRITAIN, 1851 (BY J. PAXTON)



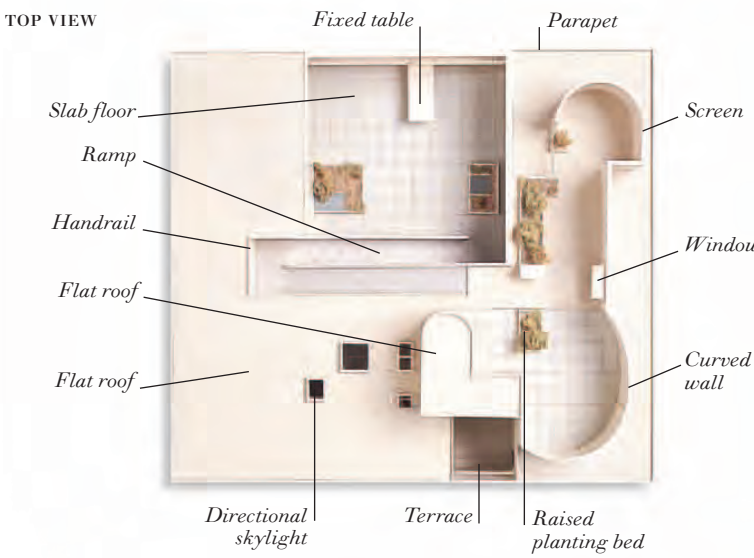
The early 20th century

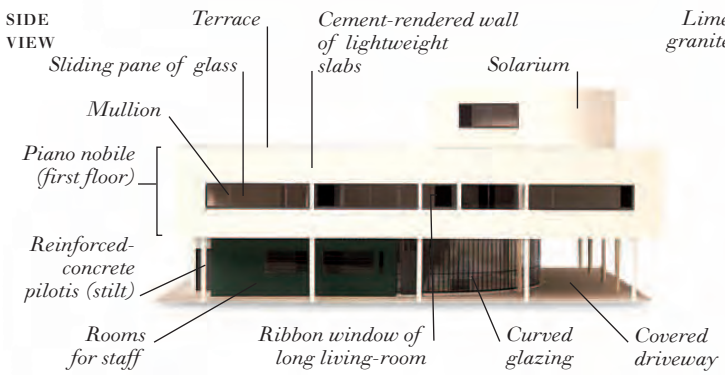
ARCHITECTURE OF THE EARLY 20TH CENTURY is notable for radical new types of steel-and-glass buildings—particularly skyscrapers—and the widespread use of steel-reinforced concrete. The steel-framed skyscraper was pioneered in Chicago in the 1880s, but did not become widespread until the first decades of the 20th century. As construction techniques were refined, skyscrapers became higher and higher; for example, the Empire State Building (right) of 1929-1931 has 102 storeys. Many buildings of this period were constructed from lightweight concrete slabs, which could be supported by cantilever beams or by pilotis (stilts), as in the Villa Savoye (below). The early 20th century also produced a great variety of architectural styles, some of which are illustrated opposite. Despite their diversity, the styles of this period generally had one thing in common: they were completely new, with few links to past architectural styles. This originality is in marked contrast to 19th-century architecture (see pp. 492-493), much of which was revivalist.

EMPIRE STATE BUILDING, NEW YORK, USA, 1929-1931 (BY R. H. SHREVE, T. LAMB, AND A. L. HARMON)

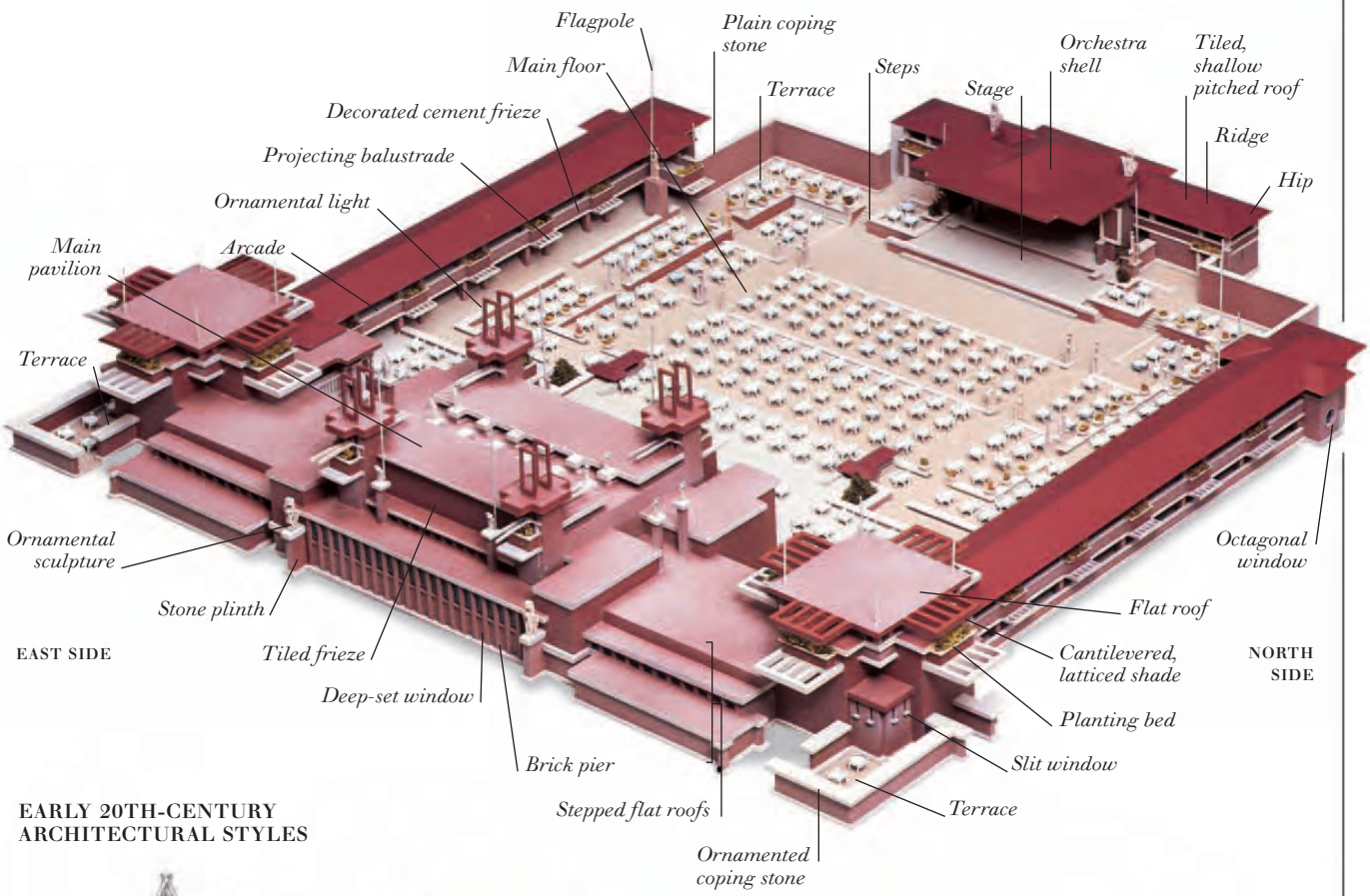


VILLA SAVOYE, POISSY, FRANCE, 1929-1931 (BY LE CORBUSIER)





MIDWAY GARDENS, CHICAGO, 1914 (BY F. L. WRIGHT)



EARLY 20TH-CENTURY ARCHITECTURAL STYLES

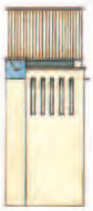
DORMER WINDOW, STUDIO ELVIRA, MUNICH, GERMANY, 1902 (ART NOUVEAU)

AEG TURBINE HALL, BERLIN, GERMANY, 1909 (DEUTSCHER WERKBUND)

ROBIE HOUSE, CHICAGO, 1909-1910 (PRAIRIE STYLE)

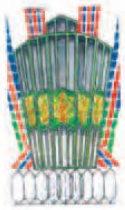
GRUNDTVIG CHURCH, COPENHAGEN, DENMARK, 1920 (EXPRESSIONIST)

VERTEX, CHRYSLER BUILDING, NEW YORK CITY, 1928-1930 (ART DECO)



TOWER, TOWN HALL, HILVERSUM, NETHERLANDS, 1930 (DUTCH CUBIST)

CASA DEL FASCIO, COMO, ITALY, 1932-1936 (GRUPPO SEVEN CUBIST)

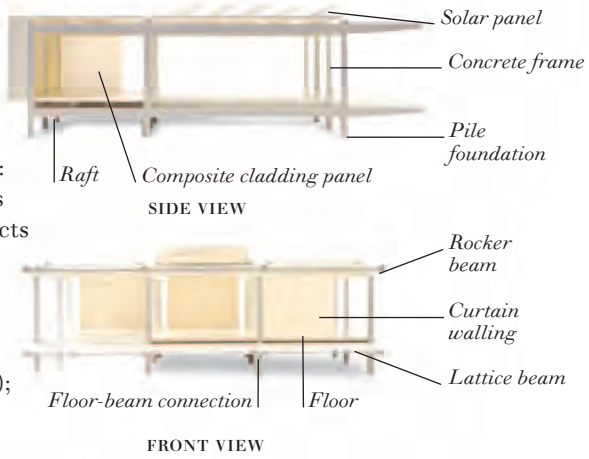


MOTIF ABOVE DOORWAY, HOOVER FACTORY, LONDON, BRITAIN, 1933 (ART DECO)

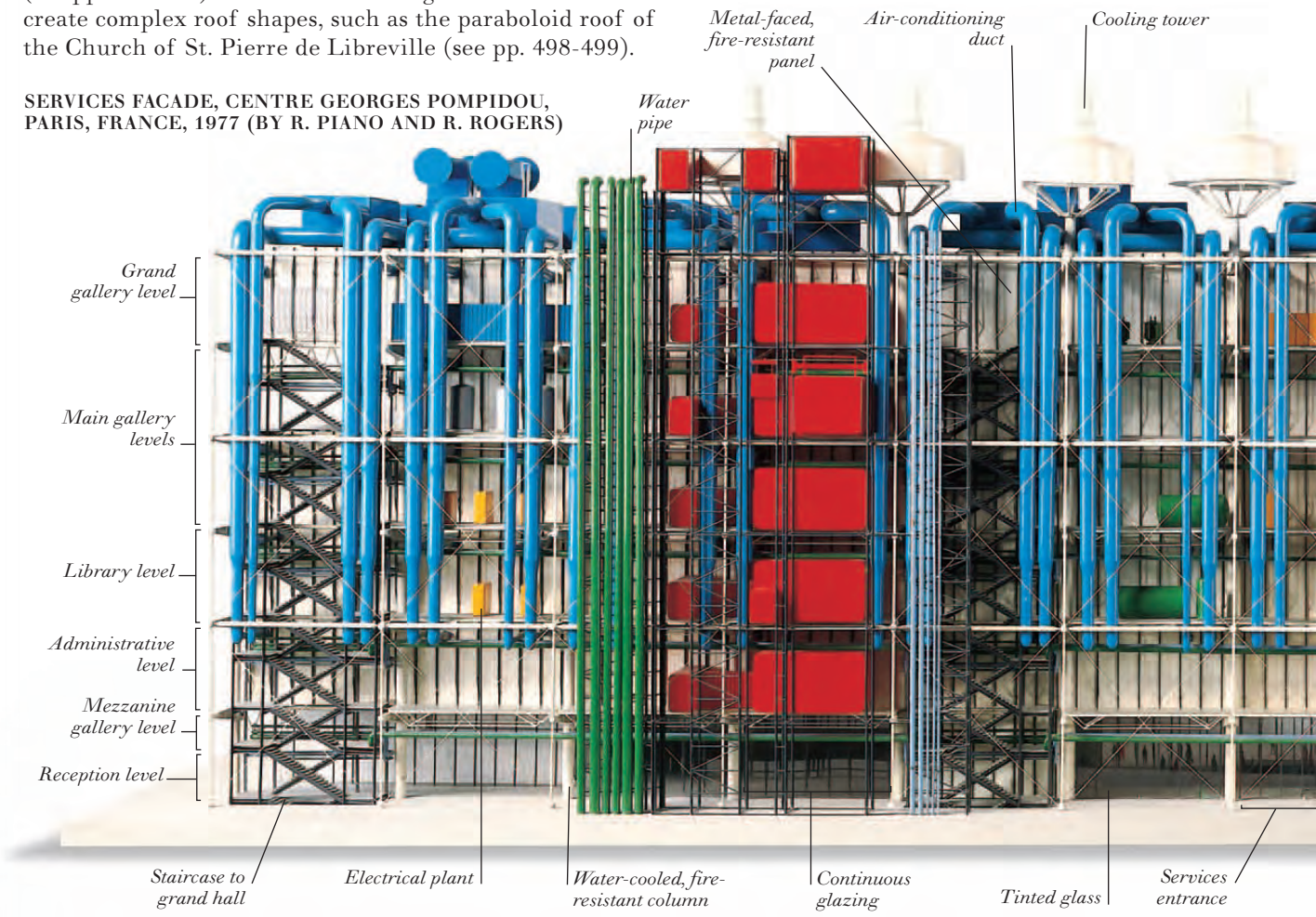
Modern buildings 1

KAWANA HOUSE, JAPAN, FROM 1987 (BY N. FOSTER)

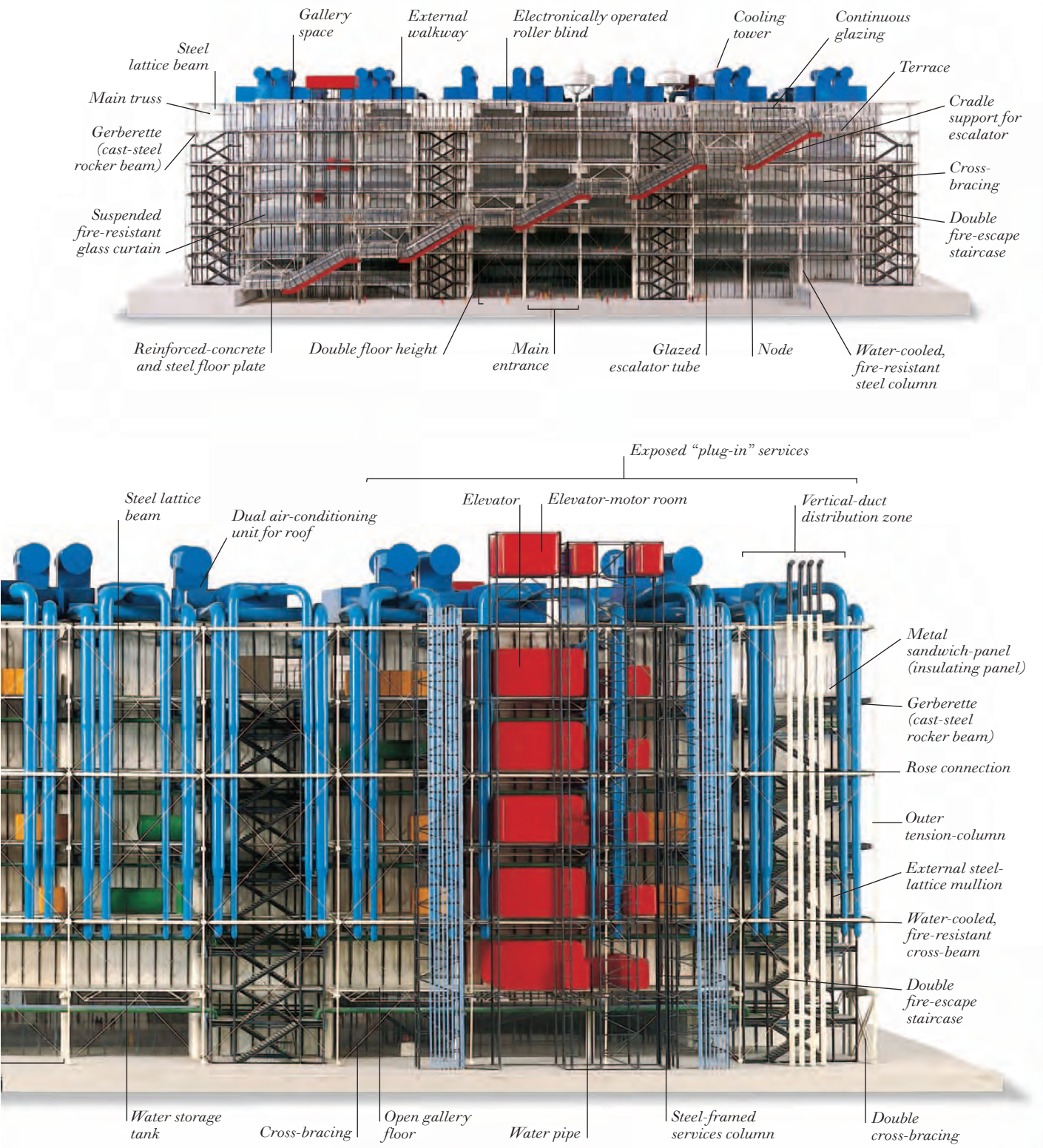
ARCHITECTURE SINCE ABOUT THE 1950s is generally known as modern architecture. One of its main influences has been functionalism—a belief that a building's function should be apparent in its design. Both the Centre Georges Pompidou (below and opposite) and the Hong Kong and Shanghai Bank (see pp. 498-499) are functionalist buildings: on each, elements of engineering and the building's services are clearly visible on the outside. In the 1980s, some architects rejected functionalism in favor of post-modernism, in which historical styles—particularly neoclassicism—were revived, using modern building materials and techniques. In many modern buildings, walls are made of glass or concrete hung from a frame, as in the Kawana House (right); this type of wall construction is known as curtain walling. Other modern construction techniques include the intricate interlocking of concrete vaults—as in the Sydney Opera House (see pp. 498-499)—and the use of high-tension beams to create complex roof shapes, such as the paraboloid roof of the Church of St. Pierre de Libreville (see pp. 498-499).



SERVICES FACADE, CENTRE GEORGES POMPIDOU, PARIS, FRANCE, 1977 (BY R. PIANO AND R. ROGERS)

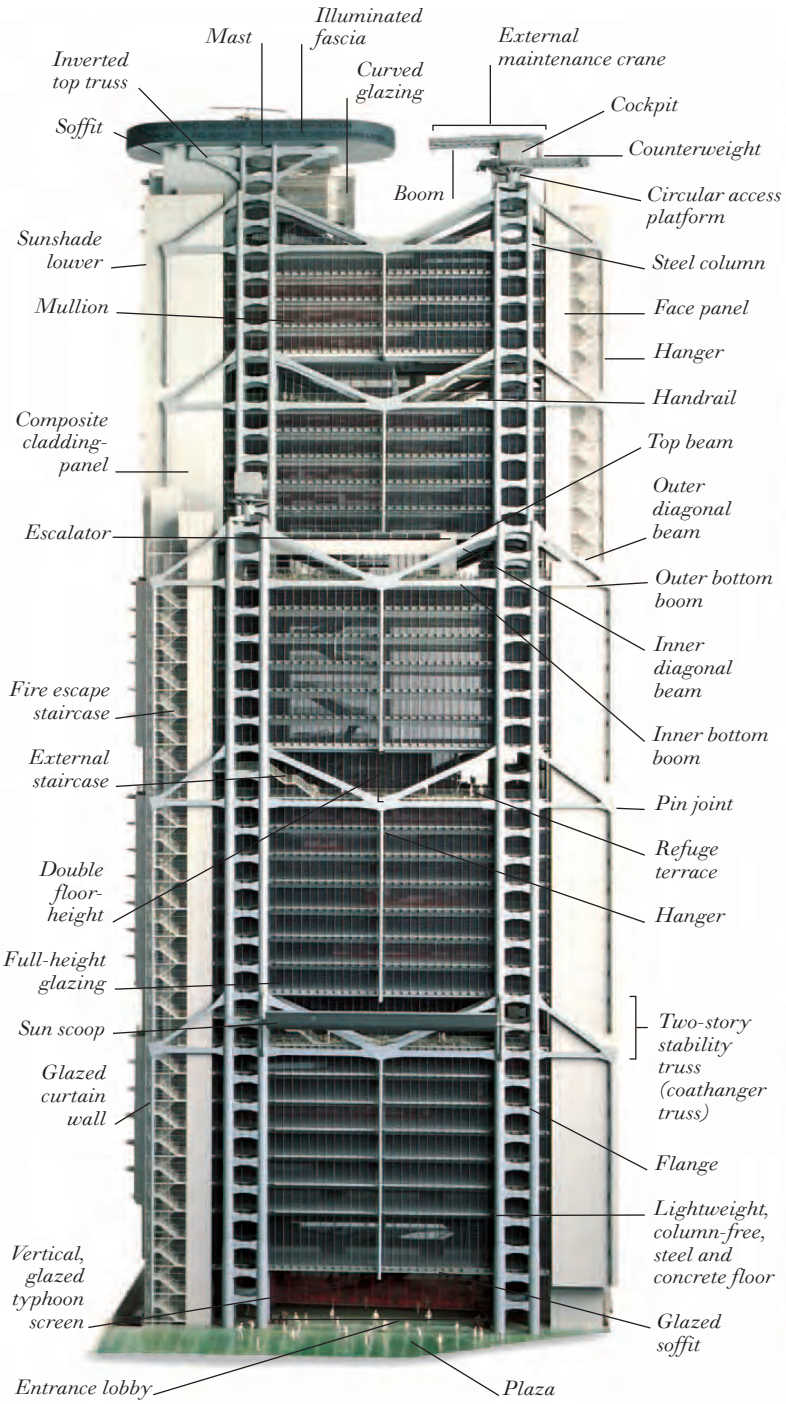


PRINCIPAL FACADE, CENTRE GEORGES POMPIDOU

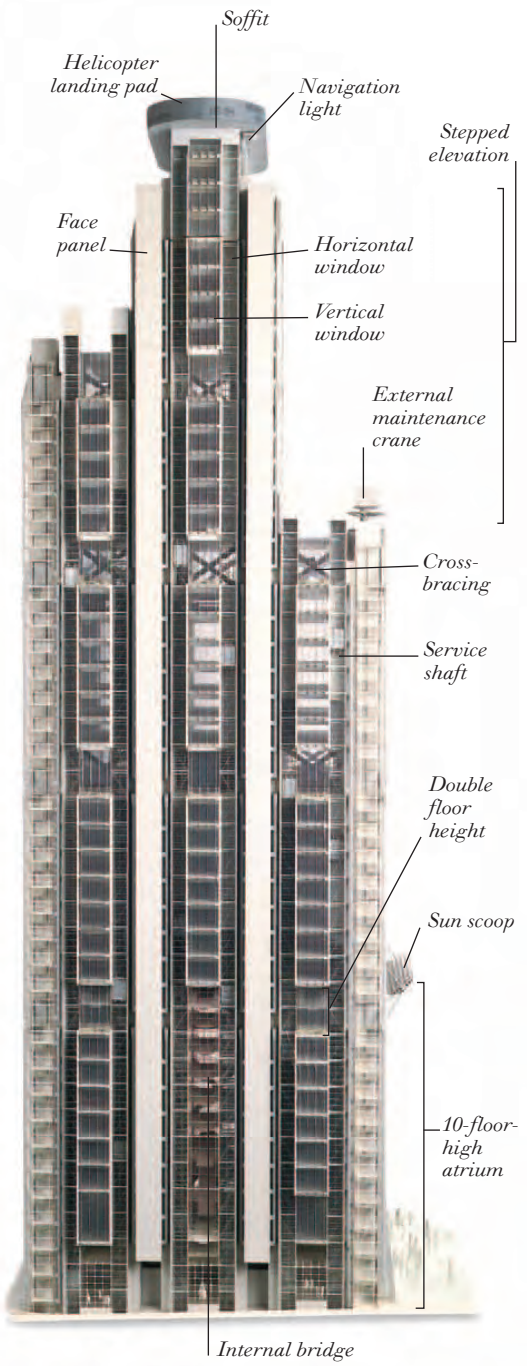


Modern buildings 2

HONG KONG AND SHANGHAI BANK, HONG KONG, 1981-1985 (BY N. FOSTER)

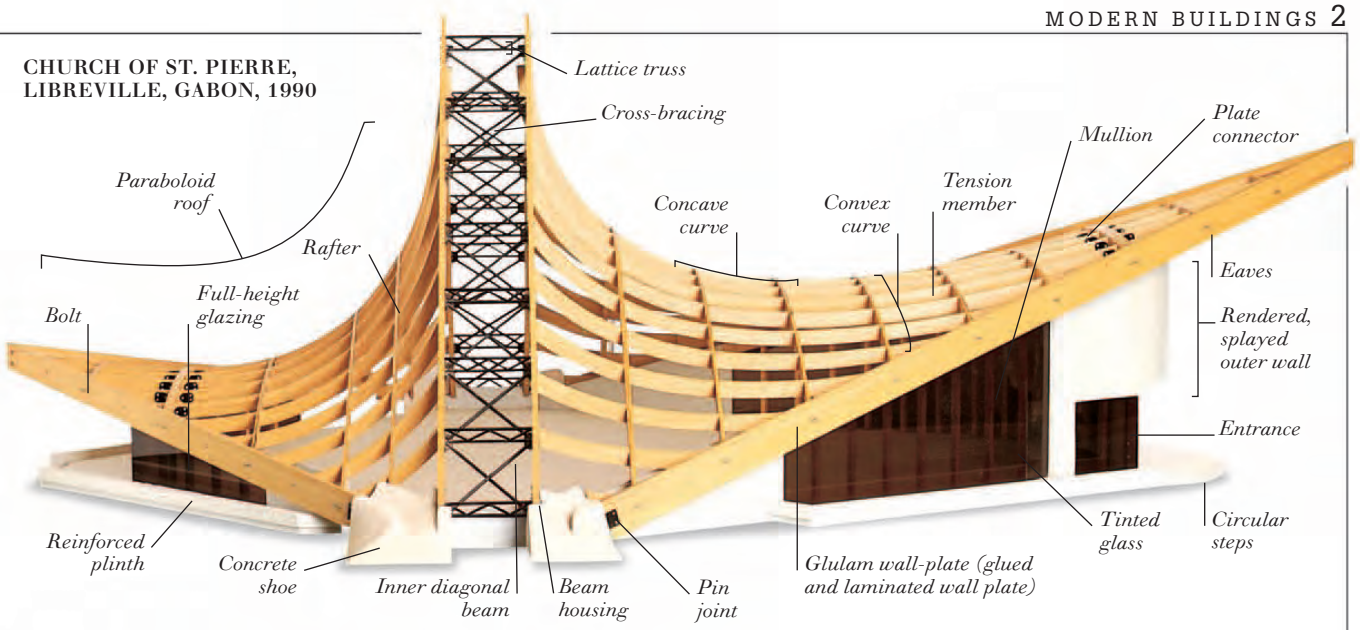


SOUTH FACADE

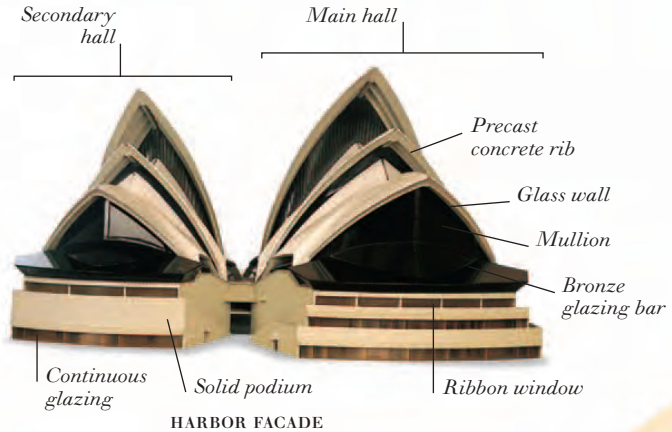


EAST SIDE

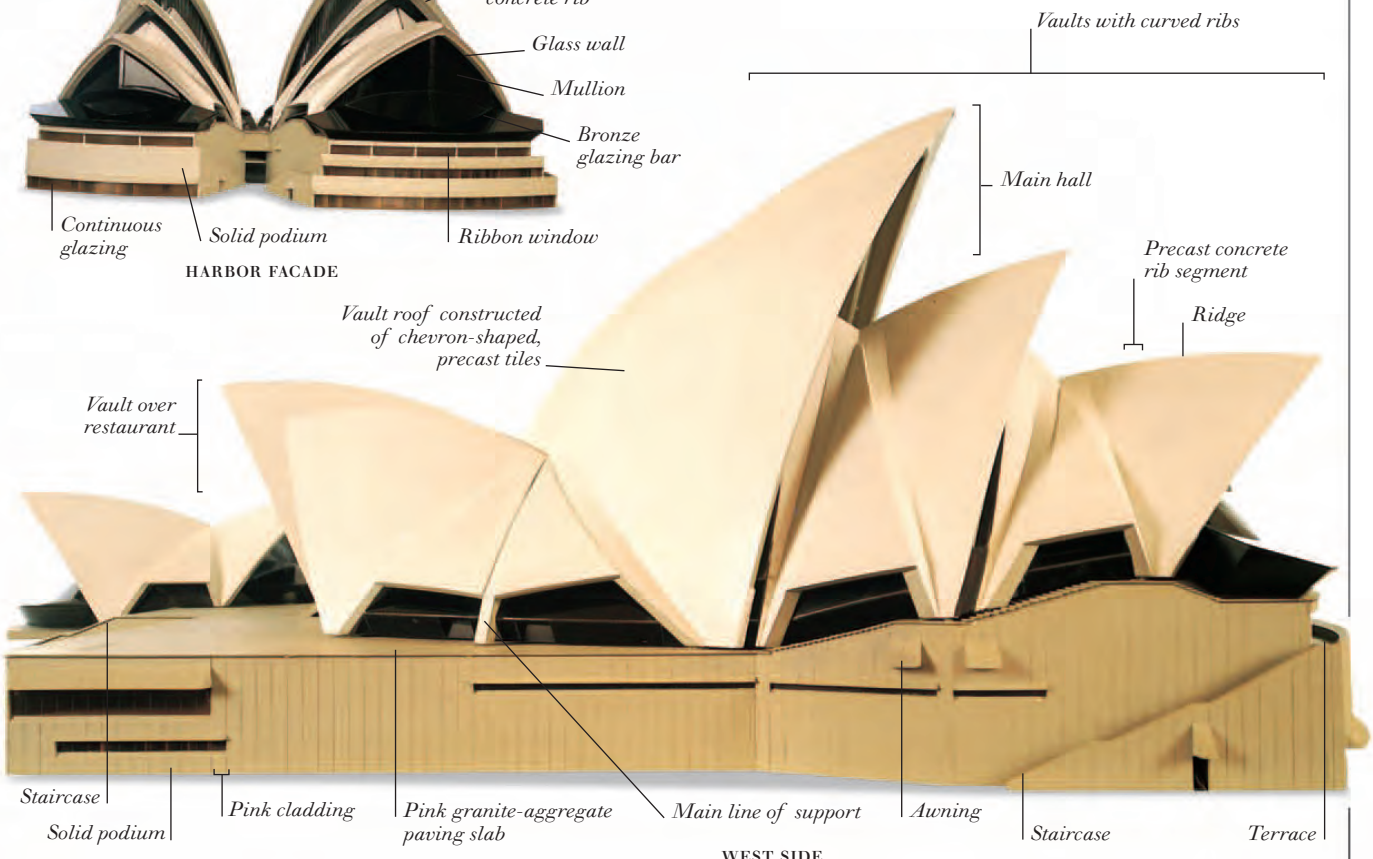
CHURCH OF ST. PIERRE, LIBREVILLE, GABON, 1990



OPERA HOUSE, SYDNEY, AUSTRALIA, 1959-1973 (BY J. UTZON)



HARBOR FACADE



WEST SIDE

B
518422

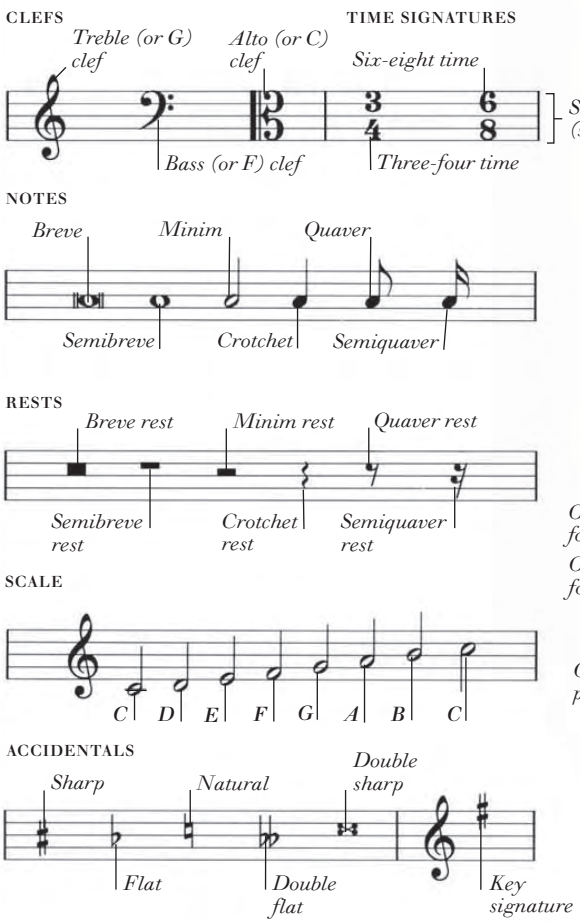
Music

Musical Notation 502
Orchestras 504
Brass Instruments 506
Woodwind Instruments 508
Stringed Instruments 510
Guitars 512
Keyboard Instruments 514
Percussion Instruments 516
Drums 518
Electronic Instruments 520

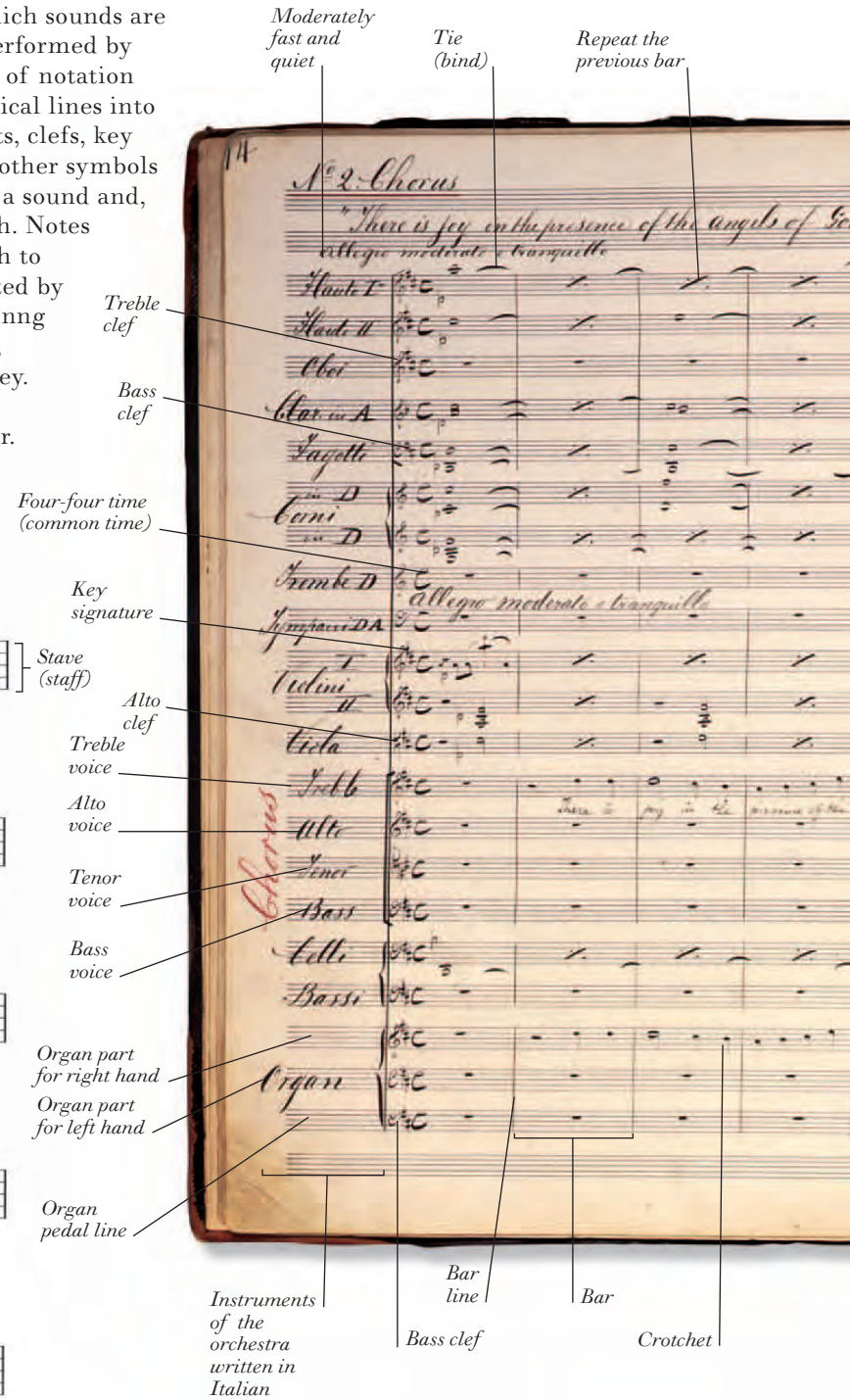
Musical notation

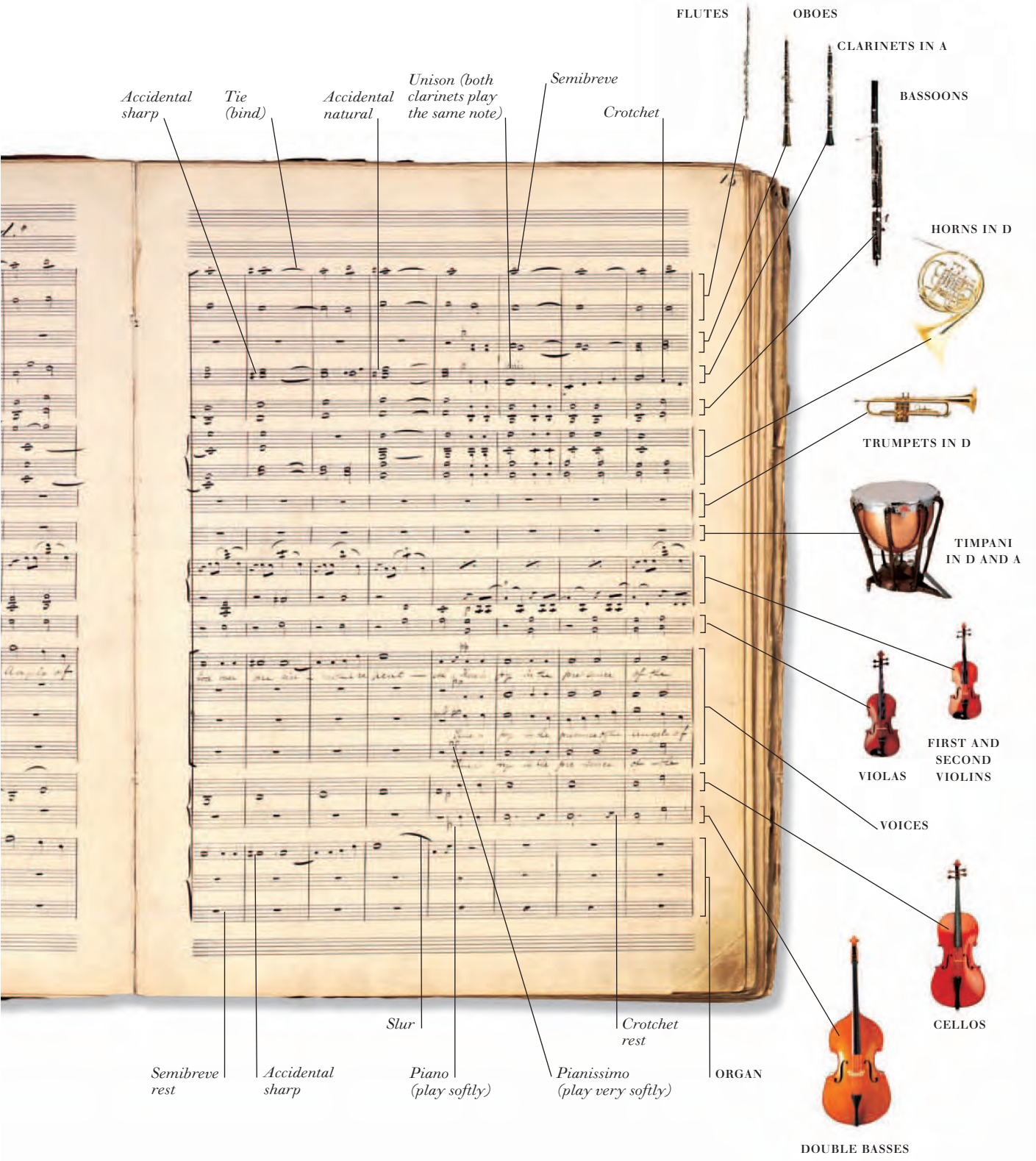
MUSICAL NOTATION IS ANY METHOD by which sounds are written down so that they can be read and performed by others. The present-day conventional system of notation uses a five-line stave (staff)—divided by vertical lines into sections known as bars—on which notes, rests, clefs, key signatures, time signatures, accidentals, and other symbols are written. A note indicates the duration of a sound and, according to its position on the stave, its pitch. Notes can be arranged on the stave in order of pitch to form a scale. A silence in the music is indicated by a rest. The clef, which is placed at the begininng of a stave, fixes the pitch. The key signature, which is placed after the clef, indicates the key. The time signature, placed after the key signature, shows the number of beats in a bar. Accidentals are used to indicate the raising or lowering of the pitch of a note.

ELEMENTS OF MUSICAL NOTATION



EXAMPLE OF AN ORIGINAL MANUSCRIPT: THE PRODIGAL SON, ARTHUR SULLIVAN, 1869




FLUTES
OBOES
CLARINETS IN A
BASSOONS
HORNS IN D
TRUMPETS IN D
TIMPANI IN D AND A
FIRST AND SECOND VIOLINS
VIOLAS
VOICES
CELLOS
DOUBLE BASSES
ORGAN
Accidental sharp
Tie (bind)
Accidental natural
Unison (both clarinets play the same note)
Semibreve
Crotchet
Slur
Crotchet rest
Semibreve rest
Accidental sharp
Piano (play softly)
Pianissimo (play very softly)

Orchestras

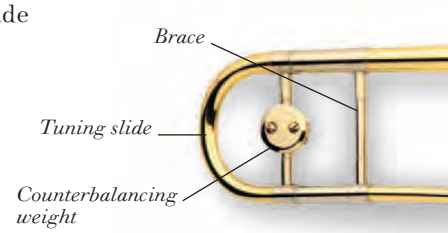
AN ORCHESTRA IS A GROUP of musicians that plays music written for a specific combination of instruments. The number and type of instruments included in the orchestra depends on the style of music being played. The modern orchestra (also known as a symphony orchestra) is made up of four sections of instruments—stringed, woodwind, brass, and percussion. The stringed section consists of violins, violas, cellos (violoncellos), double basses, and sometimes a harp (see pp. 510-511). The main instruments of the woodwind section are flutes, oboes, clarinets, and bassoons—the piccolo, cor anglais, bass clarinet, saxophone, and double bassoon (contrabassoon) can also be included if the music requires them (see pp. 508-509). The brass section usually consists of horns, trumpets, trombones, and the tuba (see pp. 506-507). The main instruments of the percussion section are the timpani (see pp. 518-519). The side drum, bass drum, cymbals, tambourine, triangle, tubular bells, xylophone, vibraphone, tam-tam (gong), castanets, and maracas can also be included in the percussion section (see pp. 516-517). The musicians are usually arranged in a semi-circle—strings spread along the front, woodwind and brass in the center, and percussion at the back. A conductor stands in front of the musicians and controls the tempo (speed) of the music and the overall balance of the sound, ensuring that no instruments are too loud or too soft in relation to the others.

EXAMPLE OF A LAYOUT OF THE INSTRUMENTS FOR A MODERN (SYMPHONY) ORCHESTRA

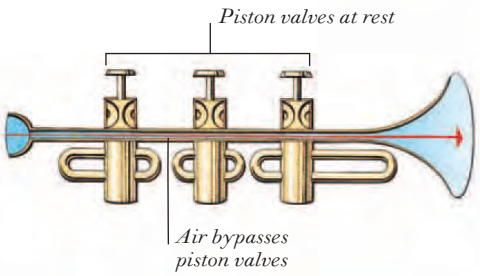
Brass instruments

BUGLE

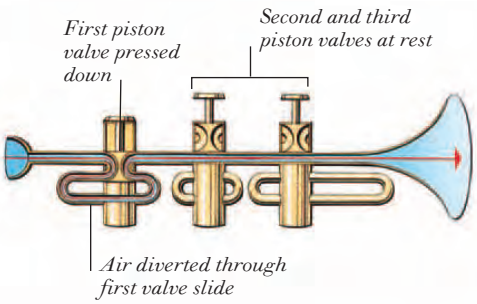
BRASS INSTRUMENTS ARE WIND INSTRUMENTS that are made of metal, usually brass. Although they appear in many different shapes and sizes, all brass instruments have a mouthpiece, a length of hollow tube, and a flared bell. The mouthpiece of a brass instrument may be cup-shaped, as in the cornet, or cone-shaped, as in the horn. The tube may be wide or narrow, mainly conical, as in the horn and tuba, or mainly cylindrical, as in the trumpet and trombone. The sound of a brass instrument is made by the player's lips vibrating against the mouthpiece, so that the air vibrates in the tube. By changing lip tension, the player can vary the vibrations and produce notes of different pitches. The range of notes produced by a brass instrument can be extended by means of a valve system. Most brass instruments, such as the trumpet, have piston valves that divert the air in the instrument along an extra piece of tubing (known as a valve slide) when pressed down. The total length of the tube is increased and the pitch of the note produced is lowered. Instead of valves, the trombone has a movable slide that can be pushed away from or drawn toward the player. The sound of a brass instrument can also be changed by inserting a mute into the bell of the instrument.



SIMPLIFIED DIAGRAM SHOWING HOW A PISTON VALVE SYSTEM WORKS

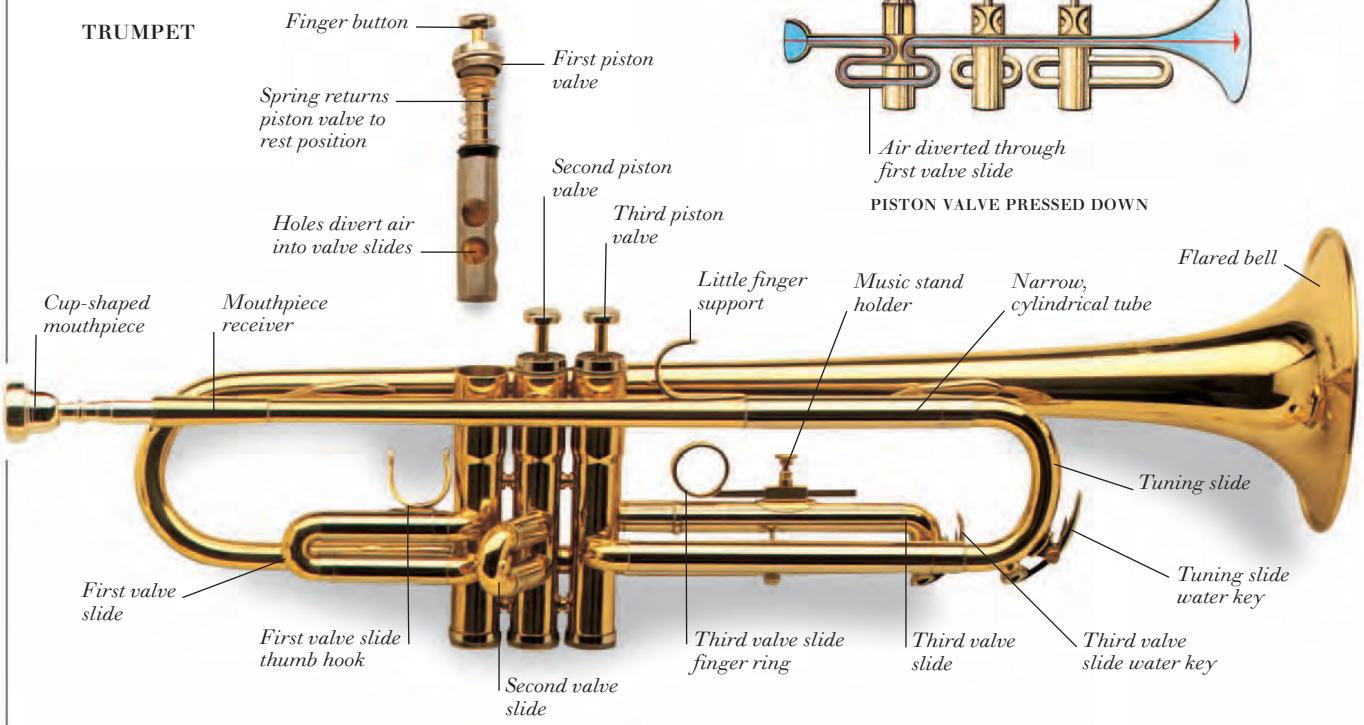


PISTON VALVES AT REST

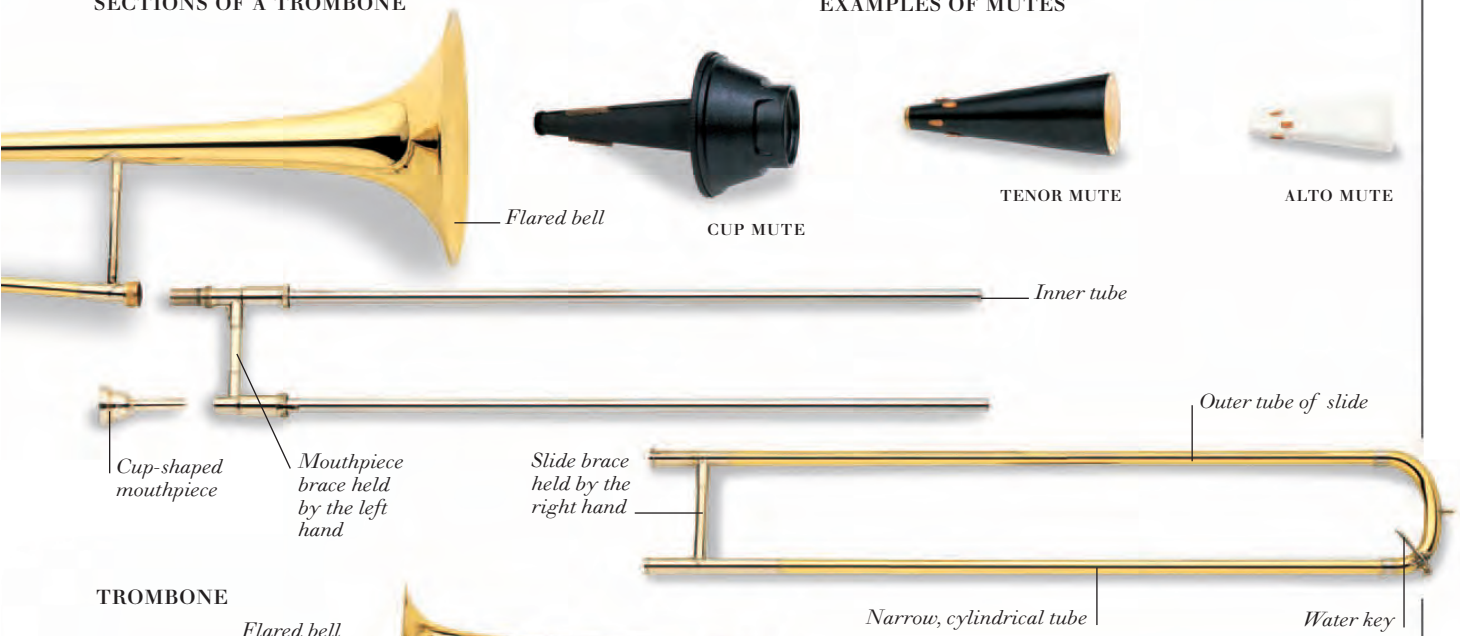


PISTON VALVE PRESSED DOWN

TRUMPET

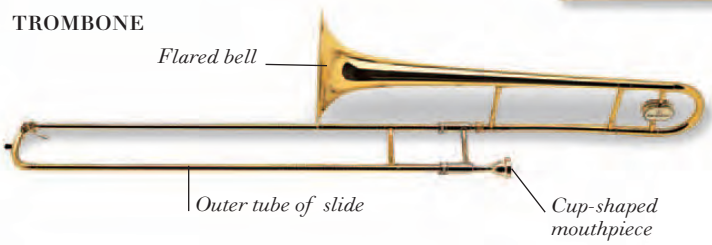


SECTIONS OF A TROMBONE



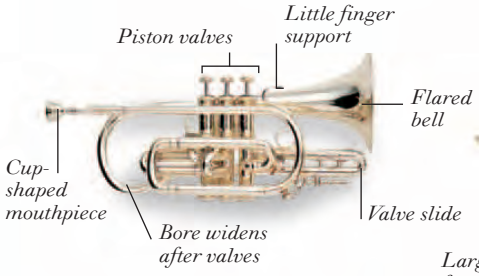
EXAMPLES OF MUTES

TROMBONE

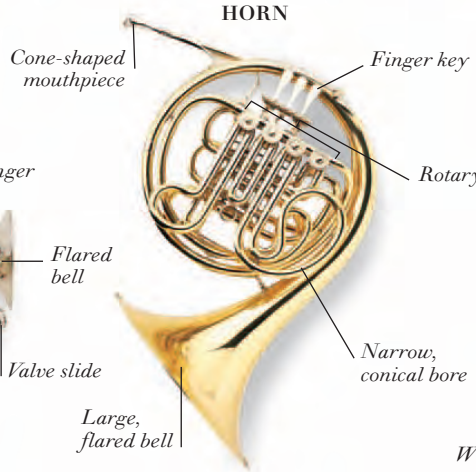


FLUGELHORN

CORNET



HORN



TUBA

Woodwind instruments

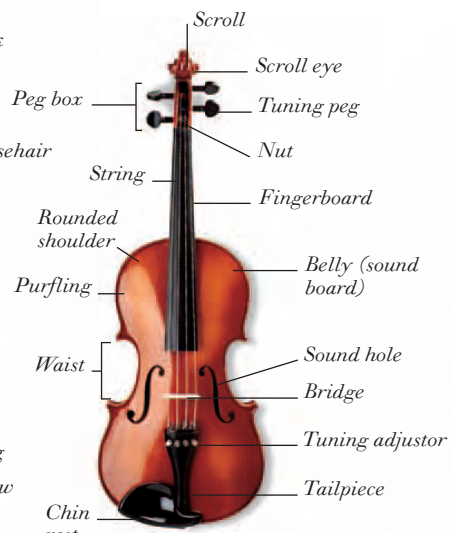
WOODWIND INSTRUMENTS ARE wind instruments that are generally made of wood, although some are made of metal or plastic. The sound of a woodwind instrument is produced by the vibration of air in a hollow tube. The air is made to vibrate by blowing across a blow hole—as in the flute and piccolo—or by blowing through a single reed—as in the clarinet and saxophone—or a double reed—as in the bassoon, cor anglais, and oboe. The pitch of a woodwind instrument can be changed by opening or closing holes cut into the tube of the instrument.

TENOR SAXOPHONE
Mouthpiece with single reed
Conical, metal tube
Upturned, flared bell
SECTIONS OF A TENOR SAXOPHONE
Mouthpiece with single reed
Ligature
Neck
Upper octave key
Key rod
KEYS FOR THE LEFT THUMB
Lower octave key
Key
Key
Key rod
KEYS FOR THE LEFT HAND
Key rod
Key
Mother-of-pearl touchpiece (button)
KEYS FOR THE RIGHT HAND
MAIN BODY OF SAXOPHONE
KEYS FOR THE RIGHT PALM
KEYS FOR THE LEFT PALM
Key
Key rod
Conical, metal tube
Upturned, flared bell
Tonehole
Mother-of-pearl touchpiece (button)
Pad made up of layers of felt and cork
Roller
Tonehole
Key guard
Cup
Key rod
Key
Metal centre of pad reflects sound
Key guard
KEYS FOR THE RIGHT LITTLE FINGER
Padded key
KEYS FOR THE LEFT LITTLE FINGER
Key guard

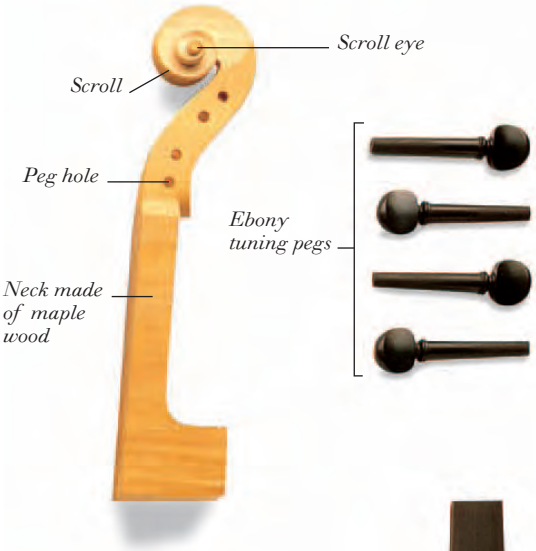
Stringed instruments

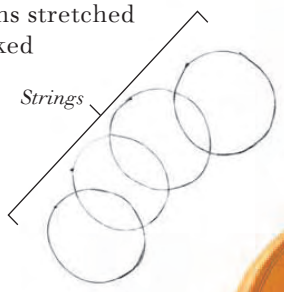
STRINGED INSTRUMENTS PRODUCE SOUND by the vibration of stretched strings. This may be done by drawing a bow across the strings, as in the violin; or by plucking the strings, as in the harp and guitar (see pp. 512-513). The four modern members of the bowed string family are the violin, viola, cello (violoncello), and double bass. Each consists of a hollow, wooden body, a long neck, and four strings. The bow is a wooden stick with horsehair stretched across its length. The vibrations made by drawing the bow across the strings are transmitted to the hollow body, and this itself vibrates, amplifying and enriching the sound produced. The harp consists of a set of strings of different lengths stretched across a wooden frame. The strings are plucked by the player's thumbs and fingers—except the little finger of each hand—which produces vibrations that are amplified by the harp's sound board. The pitch of the note produced by any stringed instrument depends on the length, weight, and tension of the string. A shorter, lighter, or tighter string gives a higher note.

VIOLIN BOW

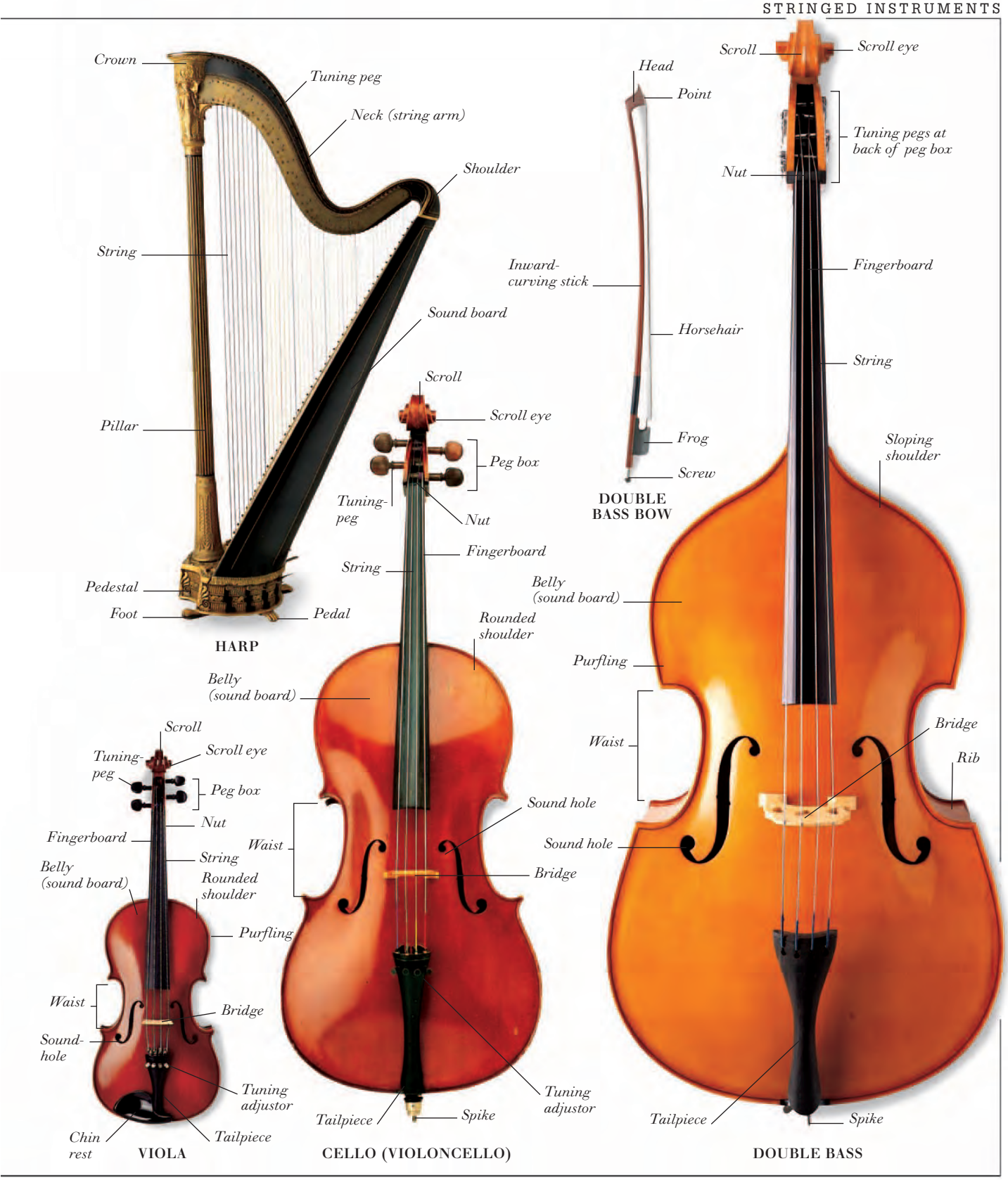


VIOLIN



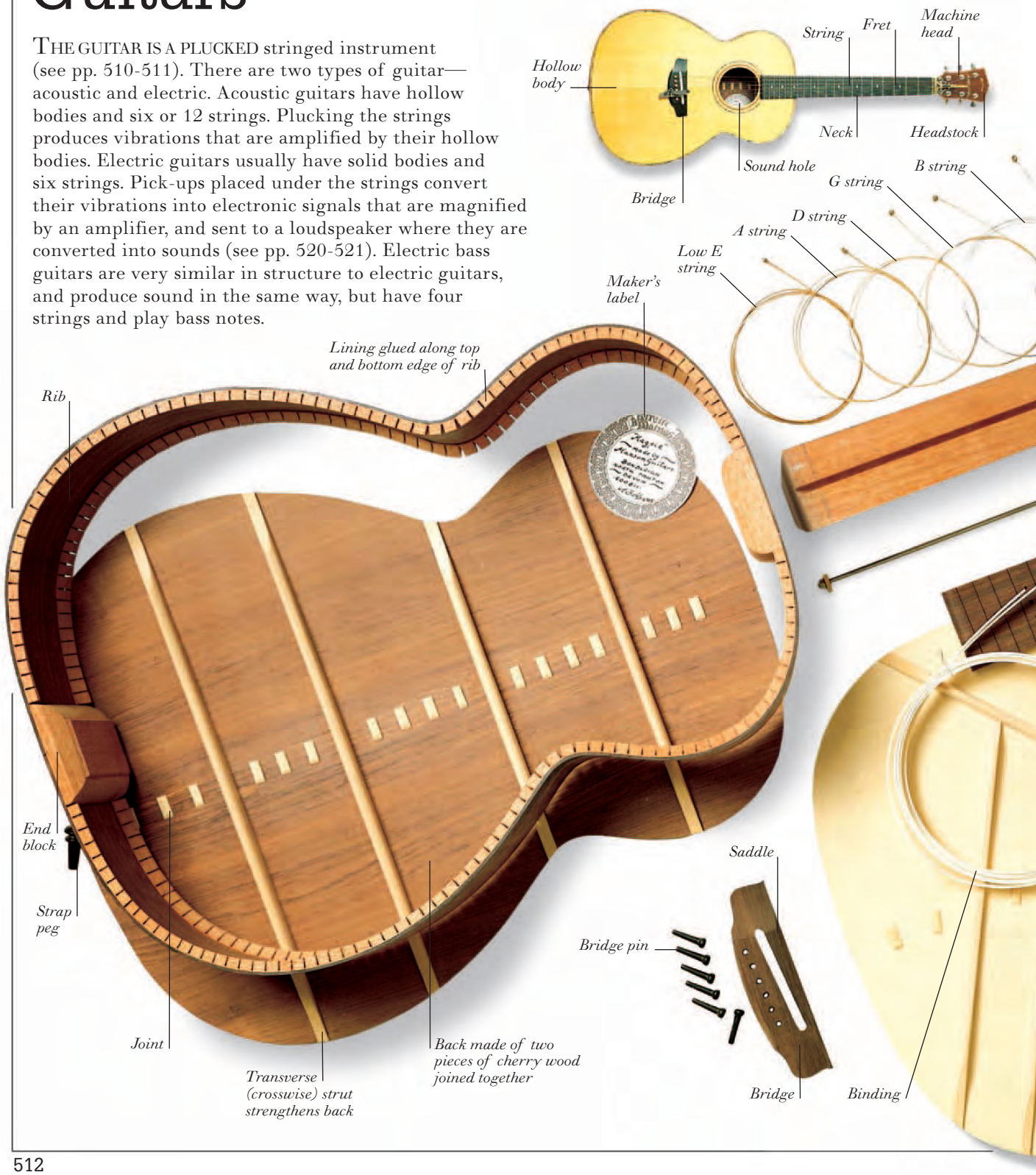


SECTIONS OF A VIOLIN


Crown
Tuning peg
Neck (string arm)
Shoulder
String
Sound board
Pillar
Pedestal
Foot
Pedal
HARP
Scroll
Scroll eye
Peg box
Tuning-peg
Nut
Fingerboard
String
Belly (sound board)
Rounded shoulder
Waist
Sound hole
Bridge
Tailpiece
Spike
Tuning adjustor
CELLO (VIOLONCELLO)
Scroll
Tuning-peg
Scroll eye
Peg box
Nut
Fingerboard
String
Belly (sound board)
Rounded shoulder
Purfling
Waist
Bridge
Sound-hole
Tuning adjustor
Chin rest
Tailpiece
VIOLA
Head
Point
Inward-curving stick
Horsehair
Frog
Screw
DOUBLE BASS BOW
Scroll
Scroll eye
Tuning pegs at back of peg box
Nut
Fingerboard
String
Sloping shoulder
Belly (sound board)
Purfling
Waist
Bridge
Rib
Sound hole
Tailpiece
Spike
DOUBLE BASS

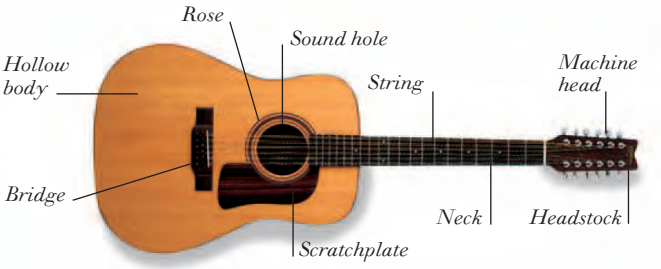
Guitars

THE GUITAR IS A PLUCKED stringed instrument (see pp. 510-511). There are two types of guitar—acoustic and electric. Acoustic guitars have hollow bodies and six or 12 strings. Plucking the strings produces vibrations that are amplified by their hollow bodies. Electric guitars usually have solid bodies and six strings. Pick-ups placed under the strings convert their vibrations into electronic signals that are magnified by an amplifier, and sent to a loudspeaker where they are converted into sounds (see pp. 520-521). Electric bass guitars are very similar in structure to electric guitars, and produce sound in the same way, but have four strings and play bass notes.

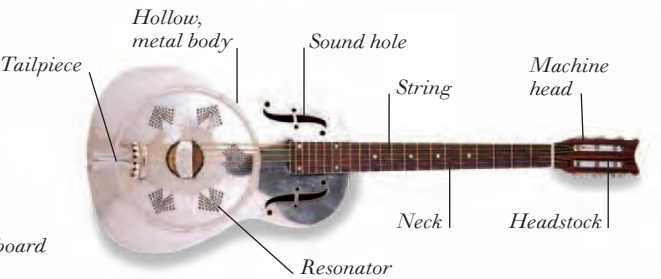


COMPONENTS OF AN ACOUSTIC GUITAR

EXAMPLES OF ACOUSTIC GUITARS

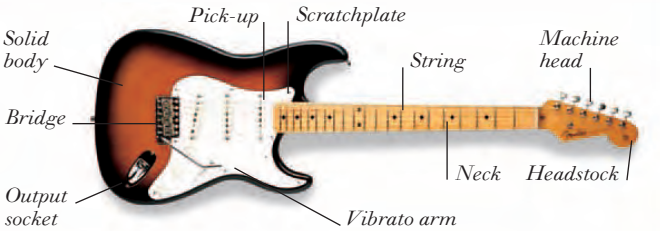


WASHBURN TWELVE-STRING

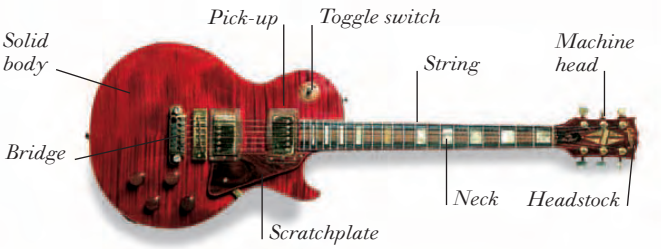


DOBRO RESONATOR

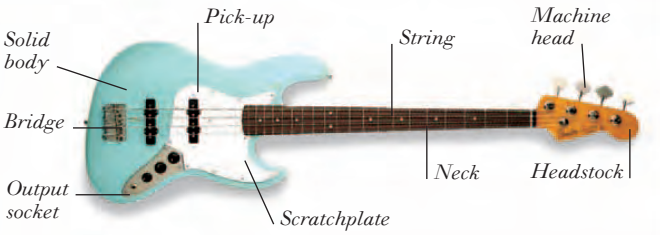
EXAMPLES OF ELECTRIC GUITARS



FENDER STRATOCASTER



GIBSON LES PAUL



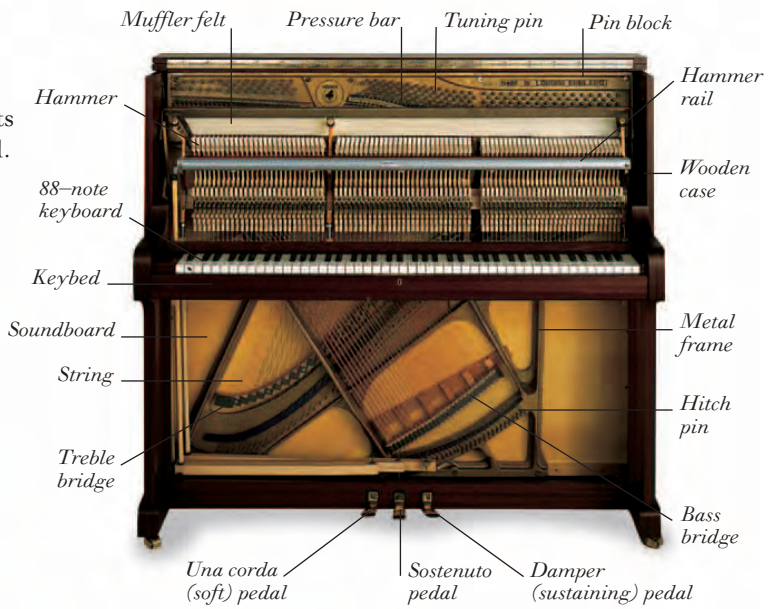
FENDER JAZZ BASS

Keyboard instruments

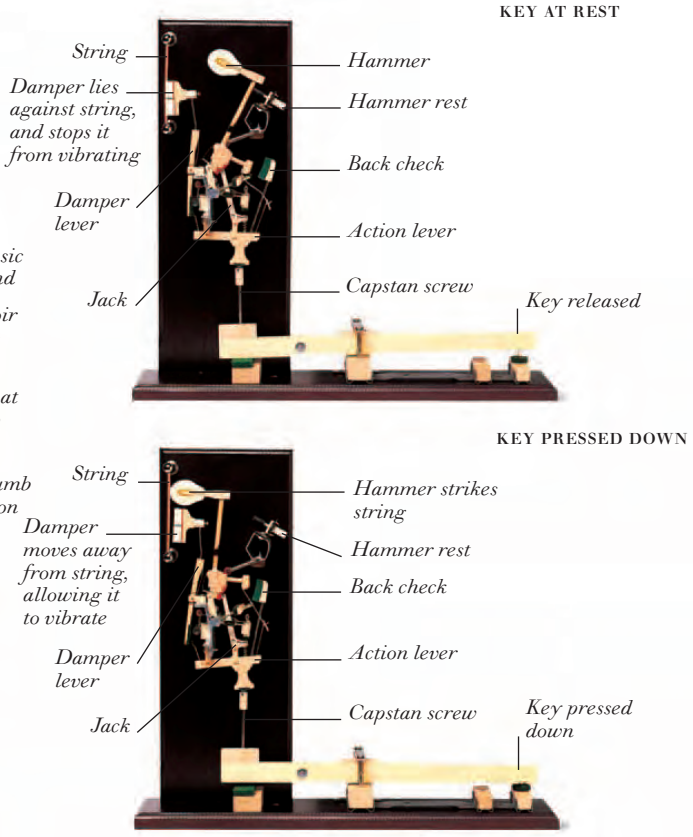
ORGAN PIPE

KEYBOARD INSTRUMENTS are instruments that are sounded by means of a keyboard. The organ and piano are two of the principal members of the keyboard family. The organ consists of pipes that are operated by one or more manuals (keyboards) and a pedal board. The pipes are lined up in rows (known as ranks or registers) on top of a wind chest. The sound of the organ is made when air is admitted into a pipe by pressing a key or pedal. The piano consists of wire strings stretched over a metal frame, and a keyboard and pedals that operate hammers and dampers. The piano frame is either vertical—as in the upright piano—or horizontal—as in the grand piano. When a key is at rest, a damper lies against the string to stop it from vibrating. When a key is pressed down, the damper moves away from the string as the hammer strikes it, causing the string to vibrate and sound a note.

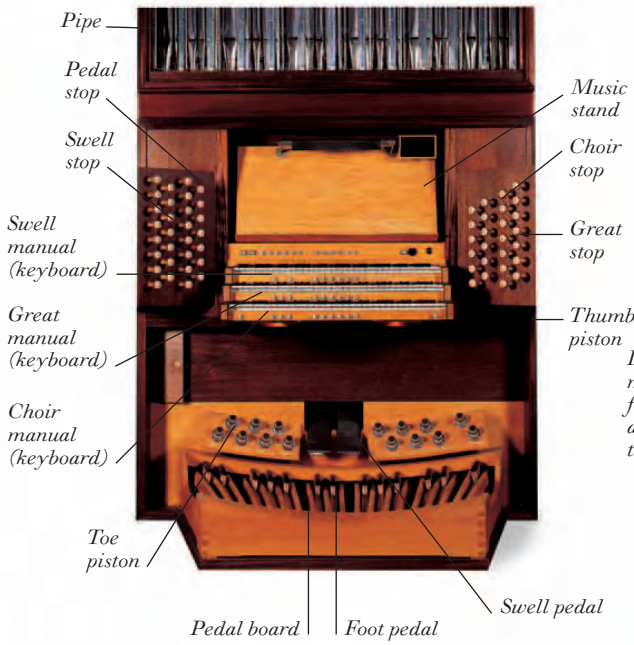
UPRIGHT PIANO

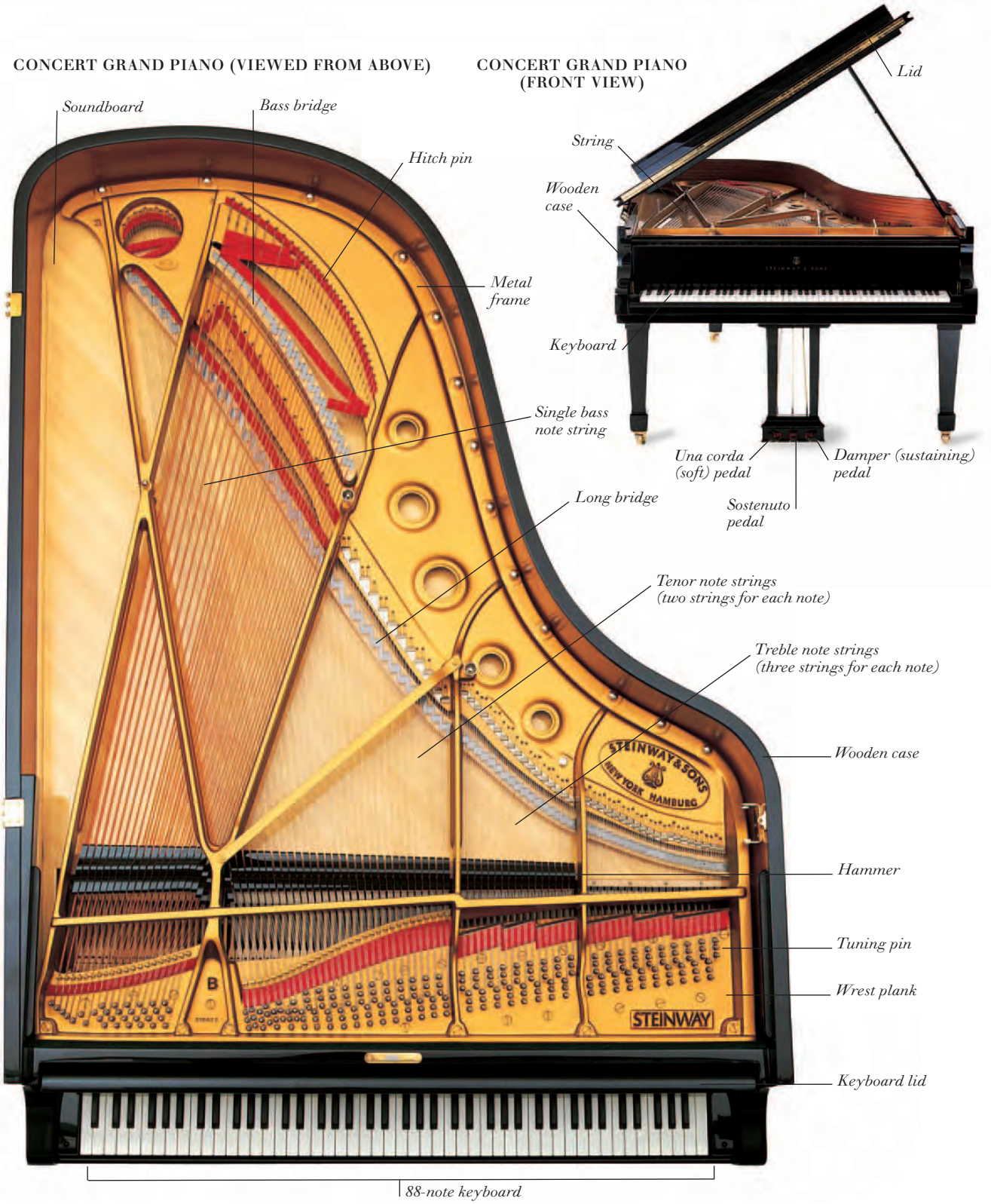


UPRIGHT PIANO ACTION



ORGAN CONSOLE



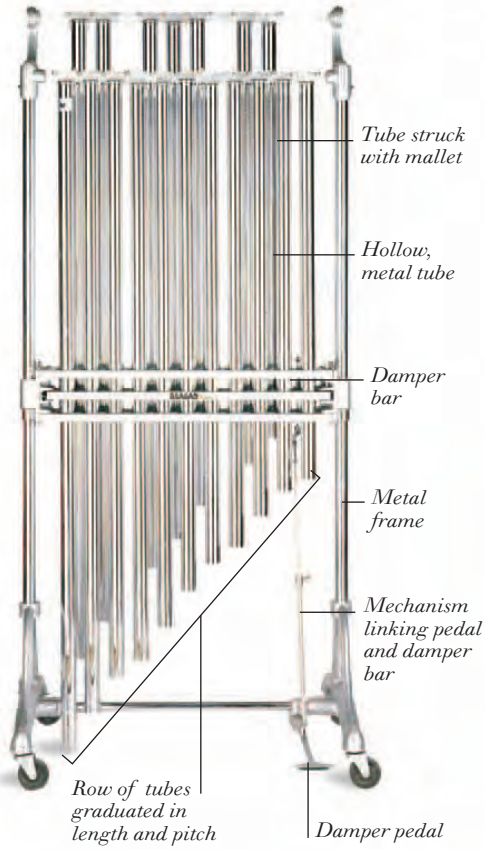

CONCERT GRAND PIANO (VIEWED FROM ABOVE)
CONCERT GRAND PIANO (FRONT VIEW)
Soundboard
Bass bridge
Hitch pin
Metal frame
Single bass note string
Long bridge
Tenor note strings (two strings for each note)
Treble note strings (three strings for each note)
Wooden case
Hammer
Tuning pin
Wrest plank
Keyboard lid
88-note keyboard
Lid
String
Wooden case
Keyboard
Una corda (soft) pedal
Sostenuto pedal
Damper (sustaining) pedal
STEINWAY & SONS
NEW YORK HAMBURG
STEINWAY

Percussion instruments

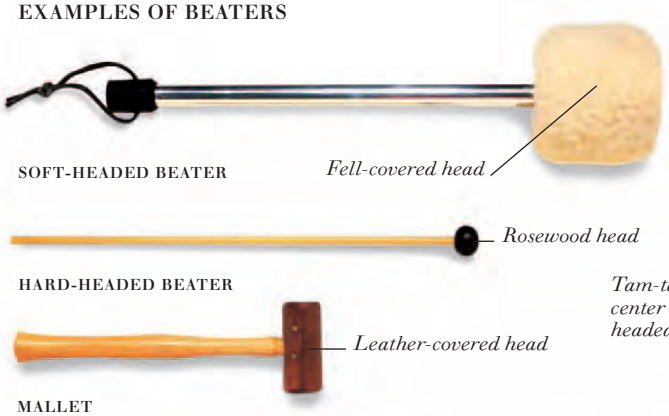
TEMPLE BLOCKS

PERCUSSION INSTRUMENTS are a large group of instruments that produce sound by being struck, shaken, scraped, or clashed together. Most percussion instruments—such as the tam-tam (gong), cymbals, and maracas—do not have a definite pitch and are used for rhythm and impact, and the distinctive timber (color) of their sound. Other percussion instruments—such as the xylophone, vibraphone, and tubular bells—are tuned to a definite pitch and can play melody, harmony, and rhythms. The xylophone and vibraphone each have two rows of bars that are arranged in a similar way to the black and white keys of a piano. Metal tubes are suspended below the bars to amplify the sound. The vibraphone has electrically operated fans that rotate in the tubes and produce a vibrato (wavering pitch) effect.

TUBULAR BELLS



EXAMPLES OF BEATERS



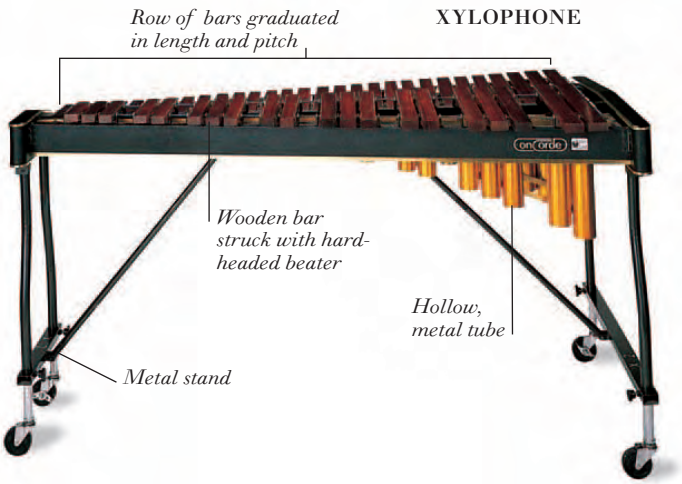
SOFT-HEADED BEATER

HARD-HEADED BEATER

MALLET

TAM-TAM (GONG)

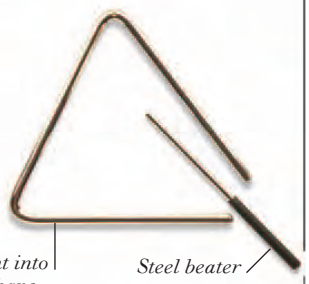
XYLOPHONE



CYMBALS

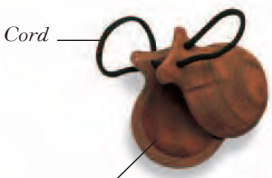
SECTIONS OF A MARACA

TRIANGLE

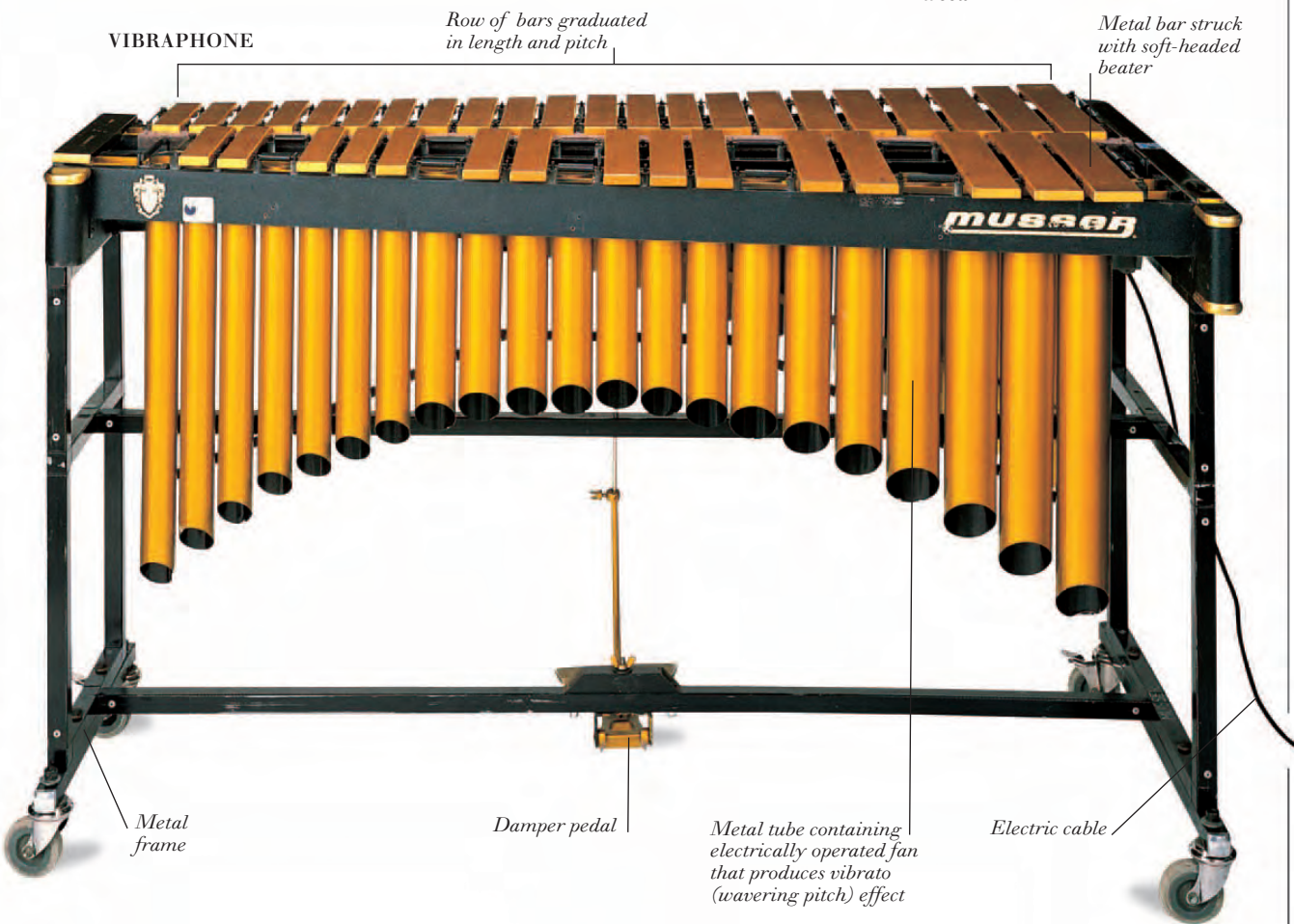


CLAVES

CASTANETS



VIBRAPHONE



Drums

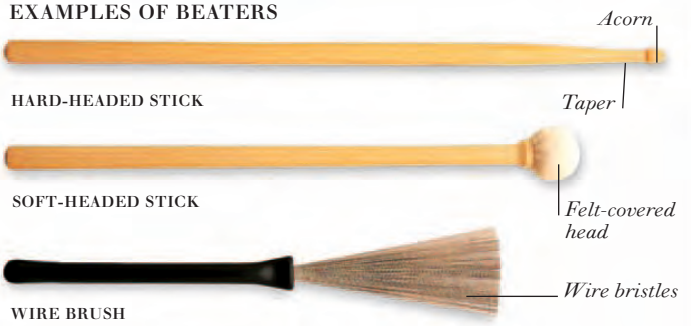
TAMBOURINE

A DRUM IS A percussion instrument that consists of a drumhead, made of skin or plastic, stretched over one or both ends of a hollow vessel (the body shell). Drums are played in most parts of the world and are made in a number of different shapes and sizes. They can be divided into three groups according to the shape of the body-shell: frame drums (e.g., tambourines), bowl-shaped drums (e.g., timpani), and tubular drums (e.g., congas). Drums are usually sounded by striking the drumhead with the hands or with beaters, such as a hard-headed stick. The drumhead vibrates, and its vibrations are amplified by the hollow body shell. The snare drum has wires—known as snares—stretched across the lower drumhead; the snares vibrate against the lower drumhead when the drum is played. Most drums, such as congas, do not have a definite pitch and can play only rhythms (see pp. 516-517). Other drums, such as timpani, have a definite pitch and can play melody, harmony, and rhythms. They can be tuned by adjusting the tension of the drumhead. Different types of drum can be combined together with other percussion instruments to form a drum set. The basic components of the drum set are bass drum, tom-toms, floor tom (tenor drum), snare drum, and cymbals.

DRUM SET

SNARE DRUM (VIEWED FROM BELOW)

EXAMPLES OF BEATERS



CONGAS

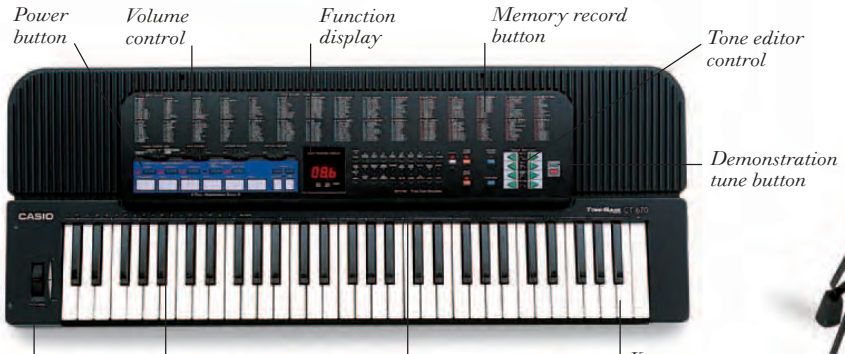
TIMPANUM (KETTLE DRUM)

Electronic instruments

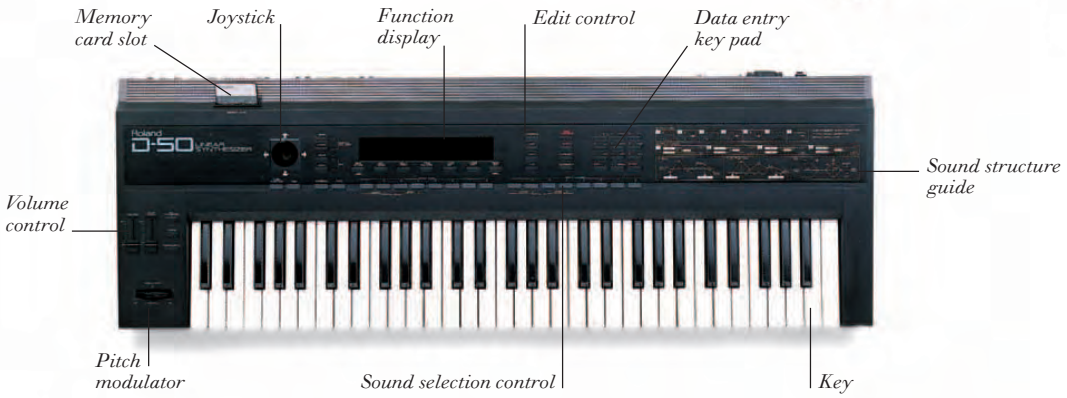
ELECTRONIC INSTRUMENTS generate electronic signals that are magnified by an amplifier and sent to a loudspeaker, where they are converted into sounds. Synthesizers, and other electronic instruments, simulate the characteristic sounds of conventional instruments, and also create entirely new sounds. Most electronic instruments are keyboard instruments, but electronic wind and percussion instruments are also popular. A digital sampler records and stores sounds from musical instruments or other sources. When the sound is played back, the pitch of the original sound can be altered. A keyboard can be connected to the sampler so that a tune can be played using the sampled sounds. With a MIDI (Musical Instrument Digital Interface) system, a computer can be linked with other electronic instruments, such as keyboards and electronic drums, to make sounds together or in sequence. It is also possible, using music software, to compose and play music on a home computer.

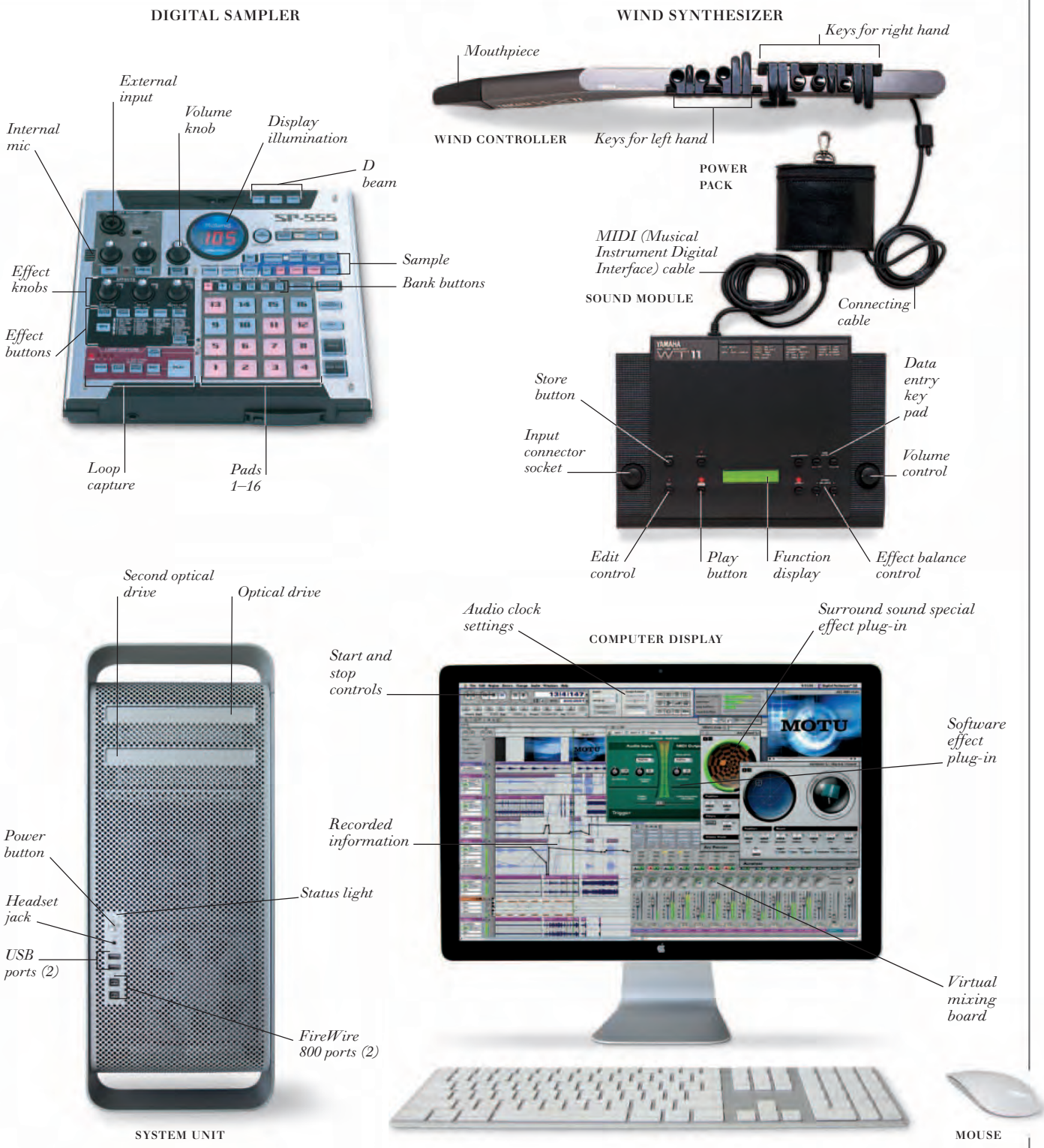
ELECTRONIC DRUMS

HOME KEYBOARD



SYNTHESIZER





COMPUTER WITH MIDI AND AUDIO SOFTWARE SEQUENCER

Willie Rand
CUSTOM

Sports

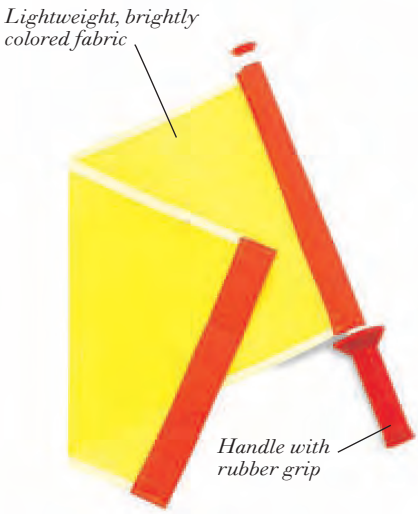
Soccer 524
Football 526
Australian Rules and Gaelic Football 528
Rugby 530
Basketball 532
Volleyball, Netball, and Handball 534
Baseball 536
Cricket 538
Hockey, Lacrosse, and Hurling 540
Track and Field 542
Racket Sports 544
Golf 546
Archery and Shooting 548
Ice Hockey 550
Alpine Skiing 552
Equestrian Sports 554
Judo and Fencing 556
Swimming and Diving 558
Canoeing, Rowing, and Sailing 560
Angling 562

Soccer

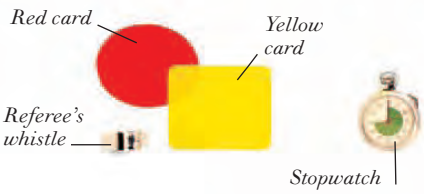
GAMES INVOLVING KICKING A BALL have a long history and were recorded in China as early as 300 BC; in medieval Europe, street football was banned as a menace to the public; only in 1863 were the rules established, specifically banning carrying the ball for all players except the goalkeeper, and separating rugby from soccer. Soccer, officially termed association football, is a team sport in which players attempt to score goals by passing and dribbling the ball down the field past opposing defenders, and kicking or heading the ball into the goal net, outwitting the defending goalkeeper. Each team consists of 10 outfield players (defenders, midfielders, and strikers) and a goalkeeper. Players from the opposing team may challenge the player in possession of the ball, but an illegal or foul tackle results in a penalty if a foul occurs inside the penalty area or a free kick if outside the penalty area. The round ball used in soccer is more easily controlled than the oval balls used in American, Canadian, and Australian rules football and in rugby. The result is a more "open" or flowing game that is played and watched by millions of people worldwide.

SOCCER FIELD

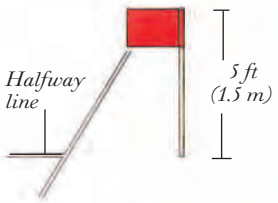
ASSISTANT REFEREE'S FLAG



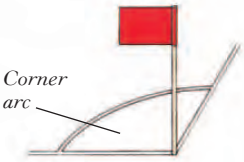
REFEREE'S EQUIPMENT



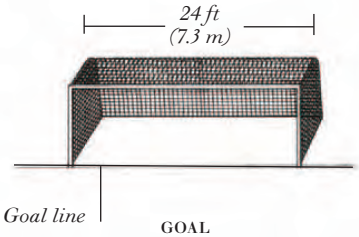
FIELD MARKINGS



HALFWAY-LINE FLAG



CORNER FLAG



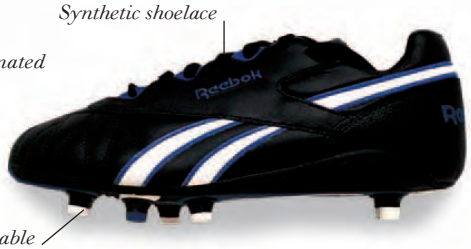
GOAL

GOALKEEPER

SOCCER STRIP

MAKING A SOCCER BALL

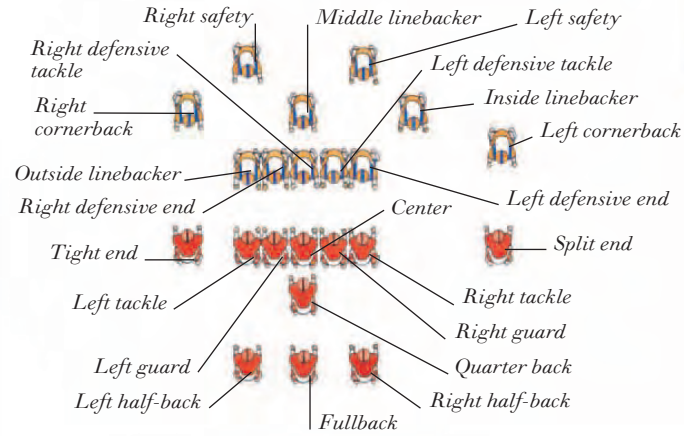
SOCCER SHOE



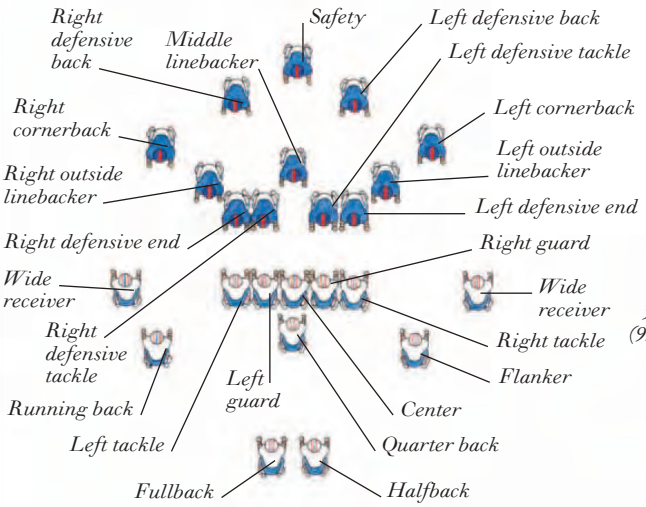
Football

IN AMERICAN AND CANADIAN FOOTBALL, the object of the game is to get the ball across the opponent's goal line, either by passing or carrying it across (a touchdown), or by kicking it between their goalposts (a field goal). An American football team has 11 players on the field at a time, although up to 40 players can appear for each side in a single game. The agile "offense" tries to score points, and the heavy hitting "defense" holds back the opposition. When in possession of the ball, a team has four chances ("downs"), to move it at least ten yards (nine meters) up the field to make a "first down." The opposition gains possession if they fail, or by tackling and intercepting the ball. Canadian football is played on a larger field, with 12 men on each side. A team has only three chances to achieve a first down. Otherwise, the game is very similar to American football. Helmets, face masks, and layers of body padding are worn by the players for protection.

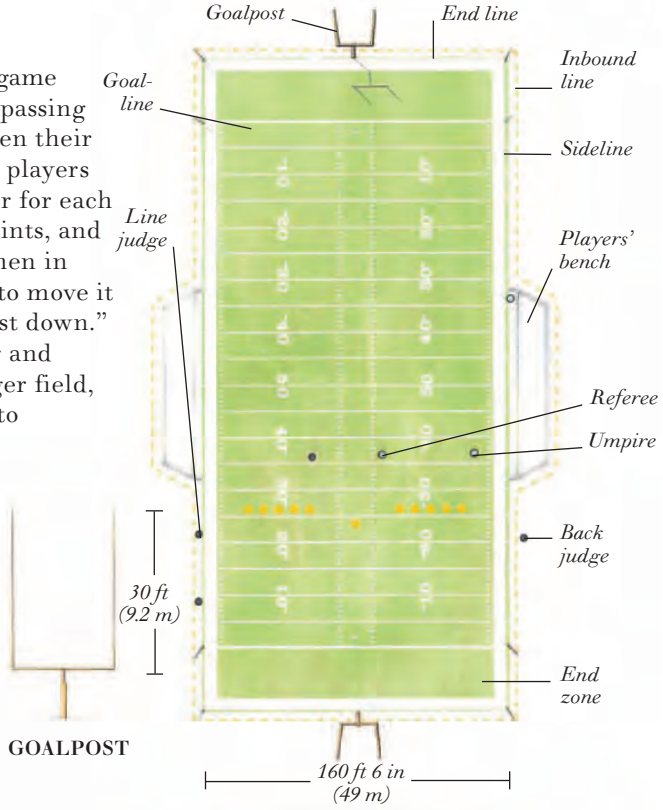
AMERICAN FOOTBALL PLAYING FORMATION



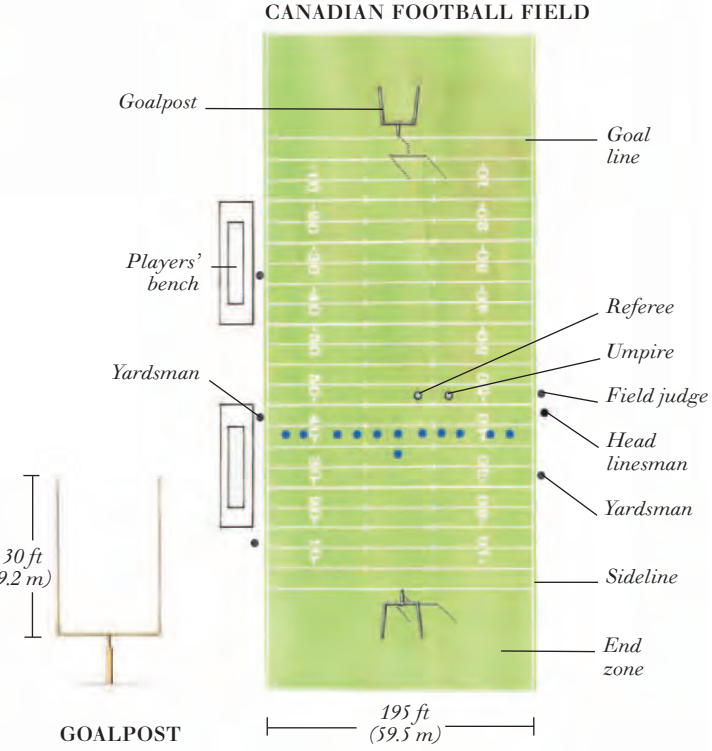
CANADIAN FOOTBALL PLAYING FORMATION



FOOTBALL FIELD

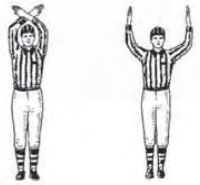


CANADIAN FOOTBALL FIELD



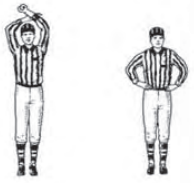
PLAYER

REFEREE'S SIGNALS



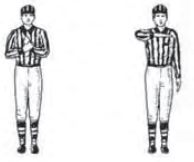
TIME OUT

TOUCHDOWN OR FIELD GOAL



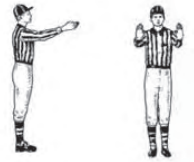
PERSONAL FOUL

OFFSIDE OR ENCROACHMENT



HOLDING

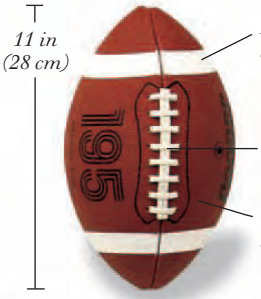
ILLEGAL MOTION



FIRST DOWN

PASS INTERFERENCE

PROTECTIVE EQUIPMENT



FOOTBALL

UPPER ARM PAD

ELBOW PAD

FINGERLESS GLOVE

SHOE

HELMET

SHOULDER PAD

RIB PADS

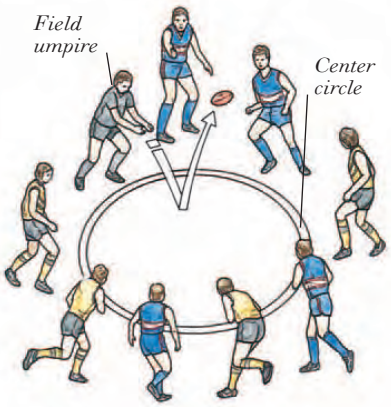
HIP PAD

PANTS

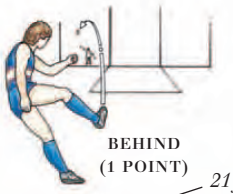
Australian rules and Gaelic football

VARIETIES OF FOOTBALL have developed all over the world and Australian rules football is considered to be one of the roughest versions, allowing full body tackles even though participants wear no protective padding. The game is played on a large, oval field by two sides, each of 18 players. Players can kick or punch the ball, which is shaped like a rugby ball, but cannot throw it. Running with the ball is permitted, as long as the ball touches the ground at least once every 10 meters. The fullbacks defend two sets of posts. Teams try to score "goals" (six points) between the inner posts or "behinds" (one point) inside the outer posts. Each game has four quarters of 25 minutes, and the team with the most points at the end of the allotted time is the winner. In Gaelic football, an Irish version of soccer (see pp. 524–525), a size 5 soccer ball is used. Each team can have 15 players on the field at a time. Players are allowed to catch, fist, and kick the ball, or dribble it using their hands or feet, but cannot throw it. Teams are awarded three points for getting the ball into the net, and one point for getting it through the posts above the crossbar. Gaelic football is rarely played outside of Ireland.

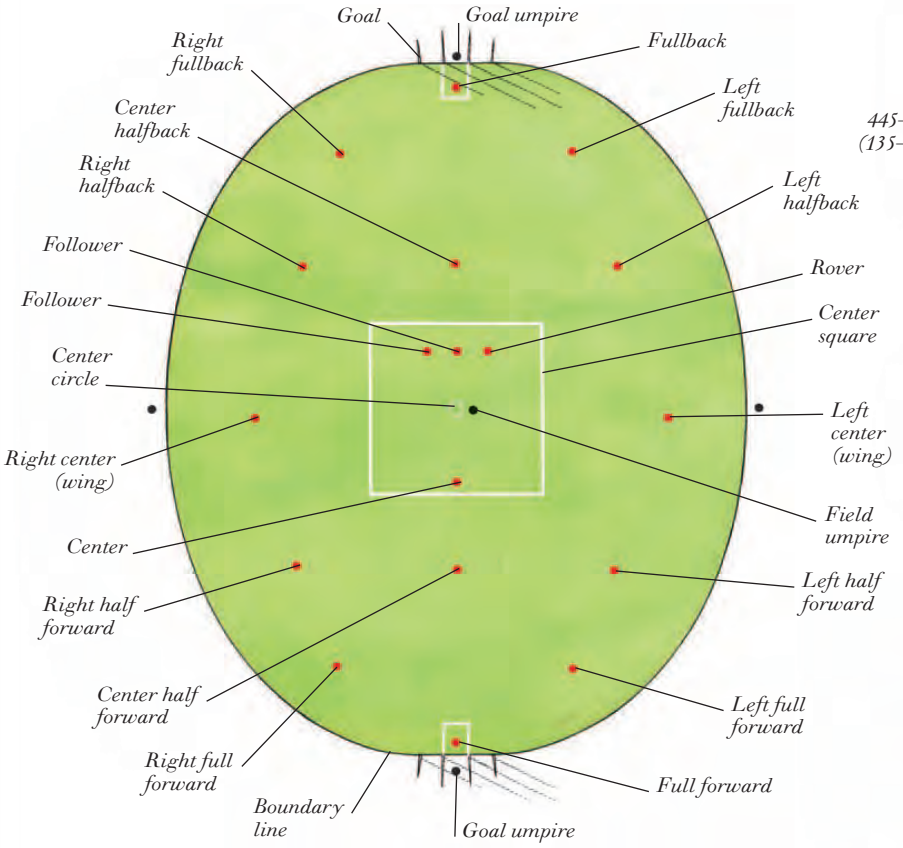
START OF PLAY

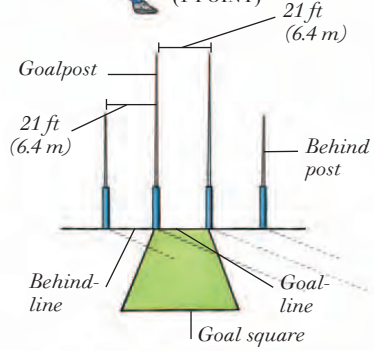


SCORING

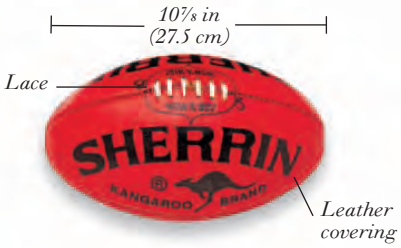


AUSTRALIAN RULES FOOTBALL FIELD





GOALPOSTS



AUSTRALIAN RULES FOOTBALL

AUSTRALIAN RULES FOOTBALL SKILLS

RUNNING WITH THE BALL

KICKING

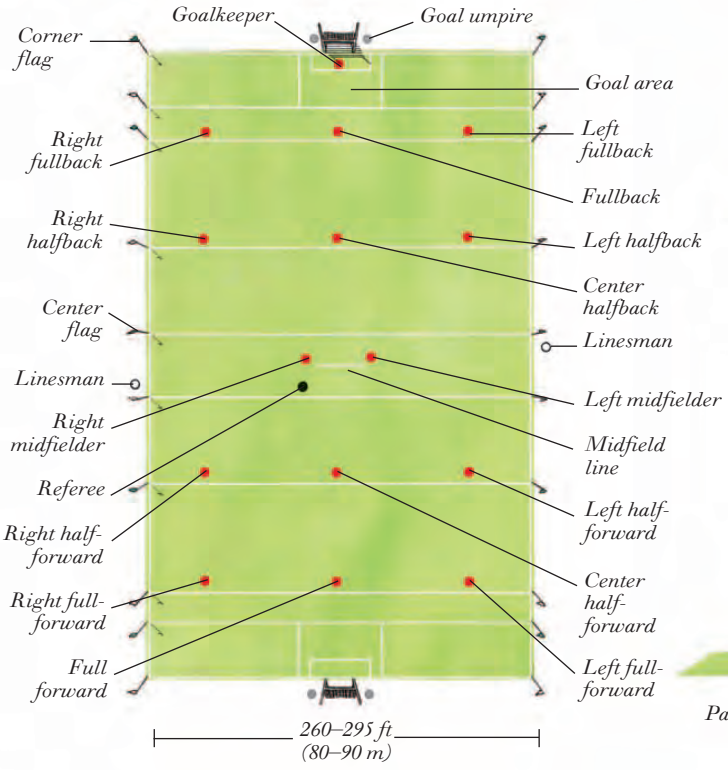
TACKLING

TAKING A MARK

PASSING THE BALL

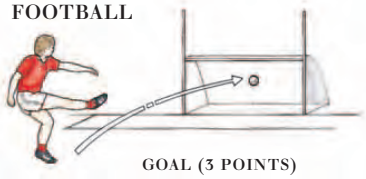
AUSTRALIAN RULES FOOTBALL UNIFORM

GAELIC FOOTBALL FIELD

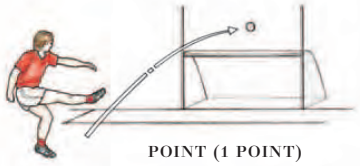


CONTROLLING THE BALL

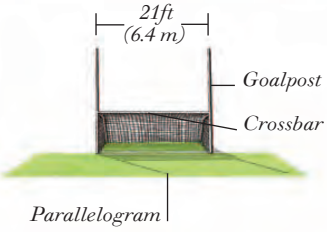
SCORING IN GAELIC FOOTBALL



GOAL (3 POINTS)



POINT (1 POINT)



GOAL

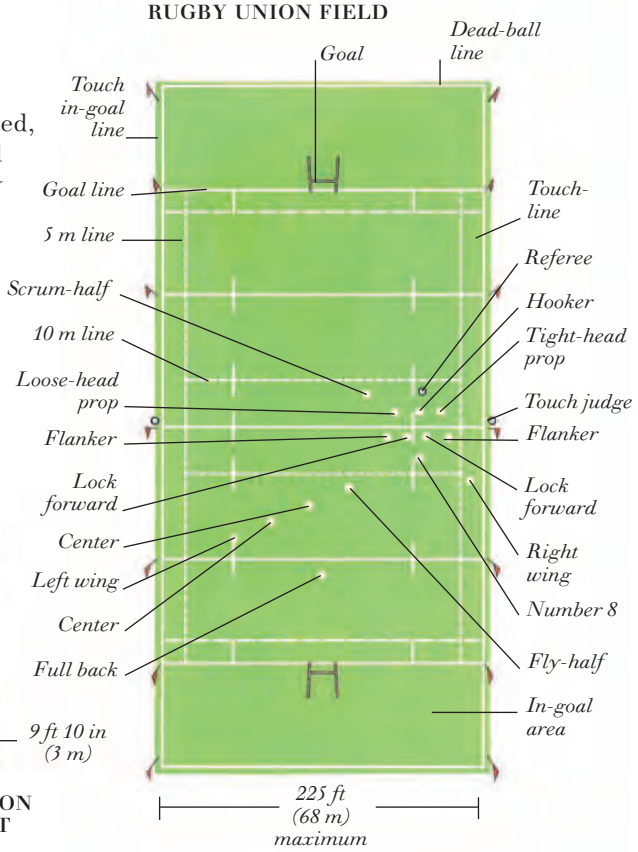
GAELIC FOOTBALL

8½–9 in (22–23 cm)

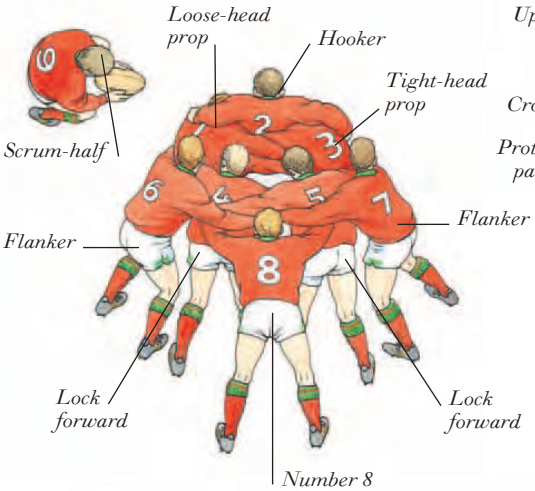
Rugby

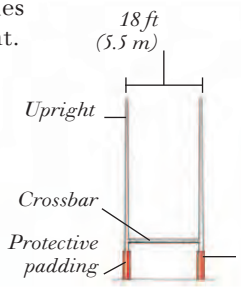
RUGBY IS PLAYED WITH AN OVAL BALL, which may be carried, thrown, or kicked. There are two codes of rugby, both played at amateur and professional levels. Rugby Union is played by two teams of 15 players. They can score points in two ways: by placing the ball by hand over the opponents' goal line (a try, scoring four points) or by kicking it over the crossbar of the opponent's goal (a conversion of a try, scoring two points; a penalty kick, scoring three points; or a dropkick, scoring three points). Rugby League developed from the Union game but is played by 13 players. In League games, a try scores four points; a conversion scores two points; a drop goal scores one point, and a penalty kick scores two points. Scrummages occur in both codes when play stops following an infringement.

RUGBY UNION FIELD



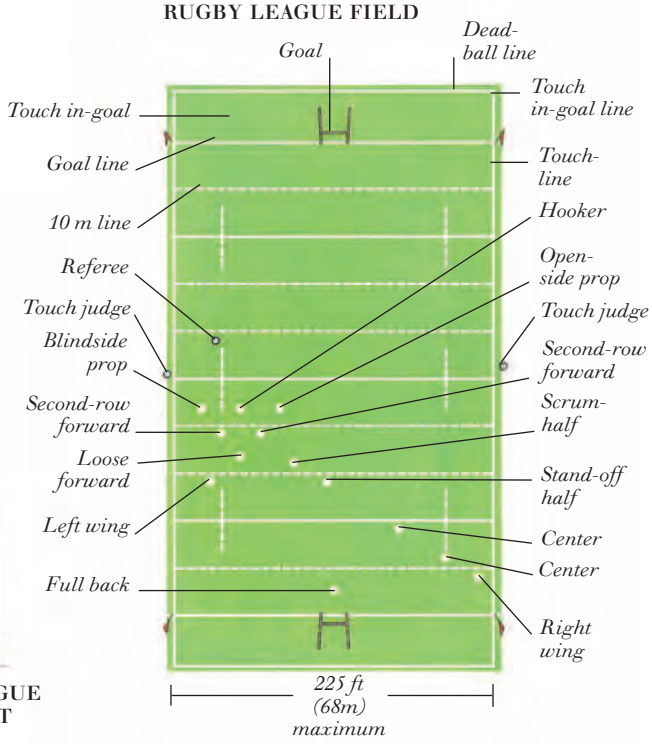
RUGBY UNION SCRUMMAGE



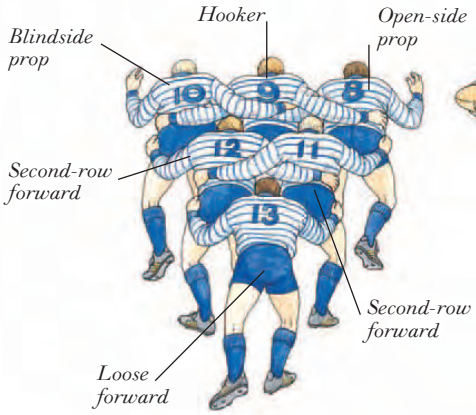


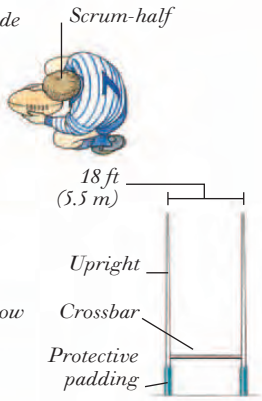
RUGBY UNION GOALPOST

RUGBY LEAGUE FIELD



RUGBY LEAGUE SCRUMMAGE





RUGBY LEAGUE GOALPOST

RUGBY SCORING AND SKILLS

GOAL

TRY

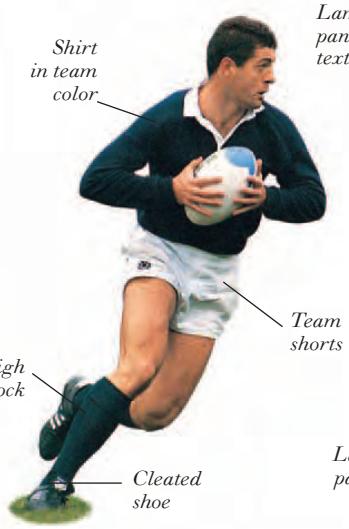
PASS

PLACE KICK

FLYING TACKLE

RUGBY SHOE

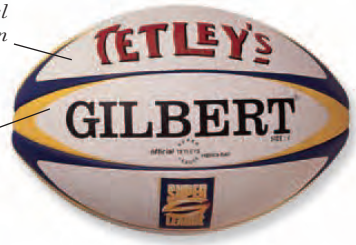
RUGBY UNION PLAYER



RUGBY UNION BALL

11–12 in (28–30 cm)

RUGBY LEAGUE BALL

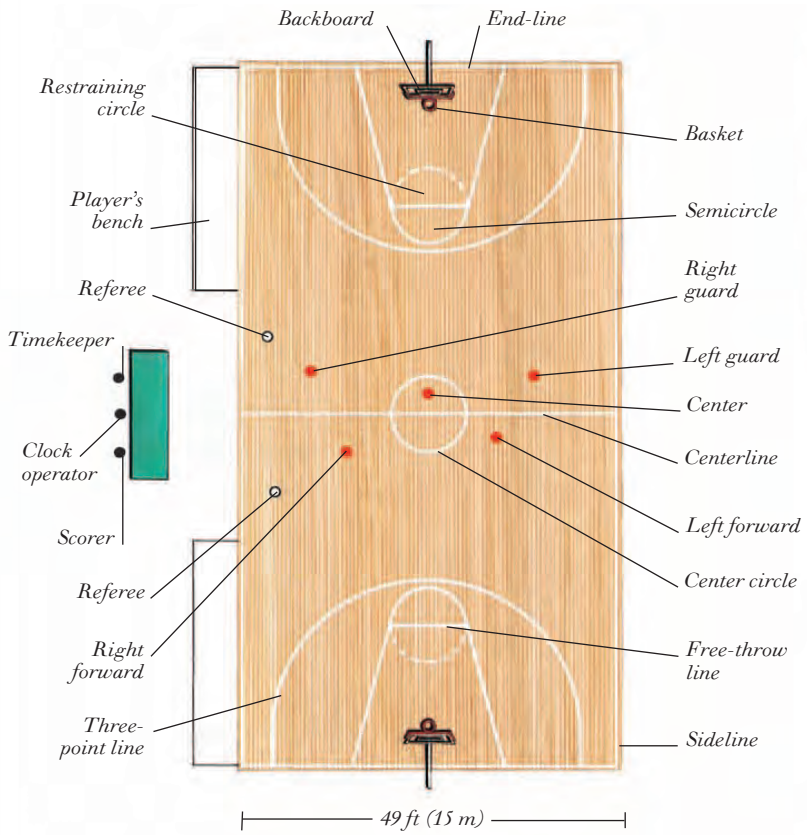


11 in (28 cm)

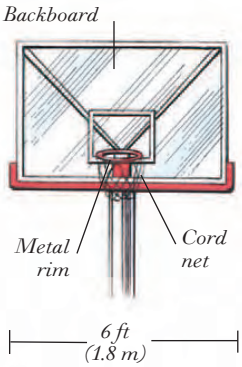
Basketball

BASKETBALL IS A BALL GAME for two teams of five players, originally devised in 1890 by James Naismath for the Y.M.C.A. in Springfield, Massachusetts. The object of the game is to take possession of the ball and score points by throwing the ball into the opposing team's basket. A player moves the ball up and down the court by bouncing it along the ground or "dribbling"; the ball may be passed between players by throwing, bouncing, or rolling. Players may not run with or kick the ball, although pivoting on one foot is allowed. The game begins with the referee throwing the ball into the air and a player from each team jumping up to try and "tip" the ball to a teammate. The length of the game and the number of periods played varies at different levels. There are amateur, professional, and international rules. No game ends in a draw. An extra period of five minutes is played, plus as many extra periods as are necessary to break the tie. In addition to the five players on court, each team has up to seven substitutes, but players may only leave the court with the permission of the referee. Basketball is a noncontact sport and fouls on other players are penalized by a throw-in awarded against the offending team; a free throw at the basket is awarded when a player is fouled in the act of shooting. Basketball is a fast-moving game, requiring both physical and mental coordination. Skillful tactical play matters more than simple physical strength and the agility of the players makes the game an excellent spectator sport.

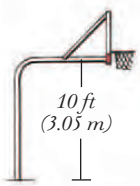
INTERNATIONAL BASKETBALL COURT



BASKET AND BACKBOARD



BASKET AND BACKBOARD STRUCTURE



BASKETBALL SKILLS

CHEST PASS

DRIBBLE

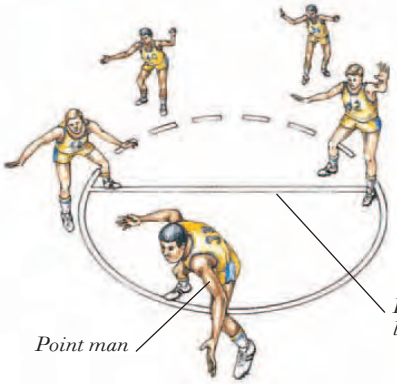
OVERHEAD PASS

LAY-UP SHOT

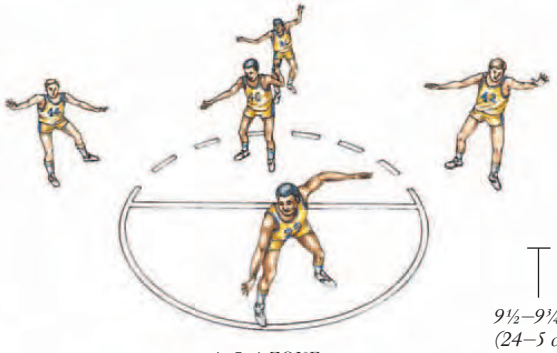
JUMP SHOT

LONG PASS

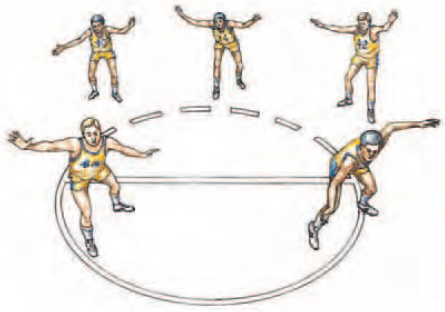
ZONE DEFENSES



1 – 2 – 2 ZONE

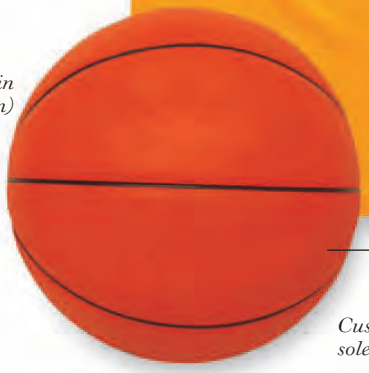


1–3–1 ZONE



2–3 ZONE

BASKETBALL JERSEY



BASKETBALL

BASKETBALL SHOE

INTERNATIONAL REFEREE'S SIGNALS

TECHNICAL FOUL

INTENTIONAL FOUL

JUMP BALL

STOP CLOCK FOR FOUL

SUBSTITUTION

STOP CLOCK

PERSONAL FOUL: NO FREE THROWS

TRAVELLING

ILLEGAL DRIBBLE

CHARGING WITH THE BALL

ONE FREE THROW

Volleyball, netball, and handball

VOLLEYBALL, NETBALL, AND HANDBALL are fast-moving team sports played with balls on courts with a hard surface. In volleyball, the object of the game is to hit the ball over a net strung across the center of the court so that it touches the ground on the opponent's side. The team of six players can take three hits to direct the ball over the net, although the same player cannot hit the ball twice in a row. Players can hit the ball with their arms, hands, or any other part of their upper body. Teams score points only while serving. The first team to score 15 points, with a two-point margin over their opponent, wins the game. Netball is one of the few sports played exclusively by women. Similar to basketball (see pp. 532–533), it is played on a slightly larger court with seven players instead of five. A team moves the ball toward the goal by throwing, passing, and catching it with the aim of throwing the ball through the opponents' goal net. Players are confined by their playing position to specific areas of the court. Team handball is one of the world's fastest games. Each side has seven players. A team moves the ball by dribbling, passing, or bouncing it as they run. Players may stop, catch, throw, bounce, or strike the ball with any part of the body above the knees. Each team tries to score goals by directing the ball past the opposition's goalkeeper into the net, which is similar to a soccer net.

VOLLEYBALL SHOTS

OVERHAND SERVE

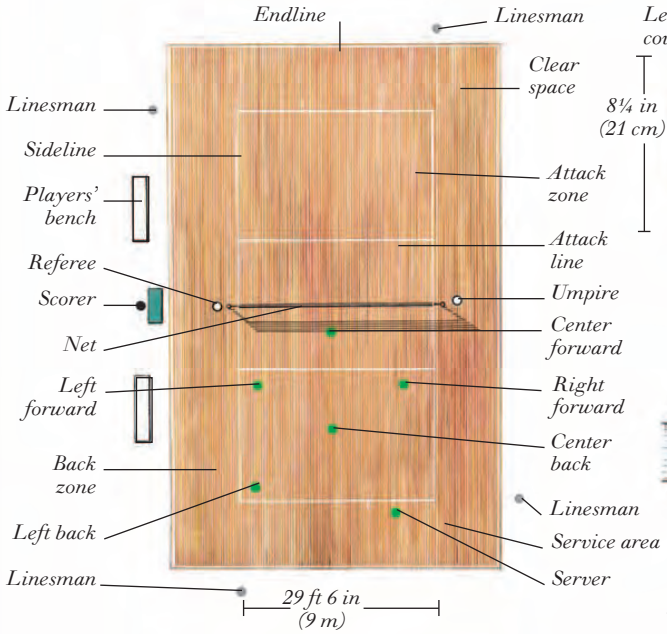
SPIKE (SMASH)

UNDERHAND SERVE

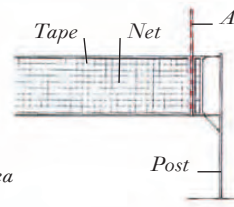
FOREARM PASS (DIG)

UNIFORM

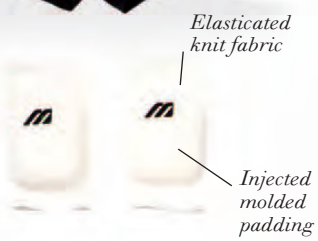
VOLLEYBALL COURT



VOLLEYBALL

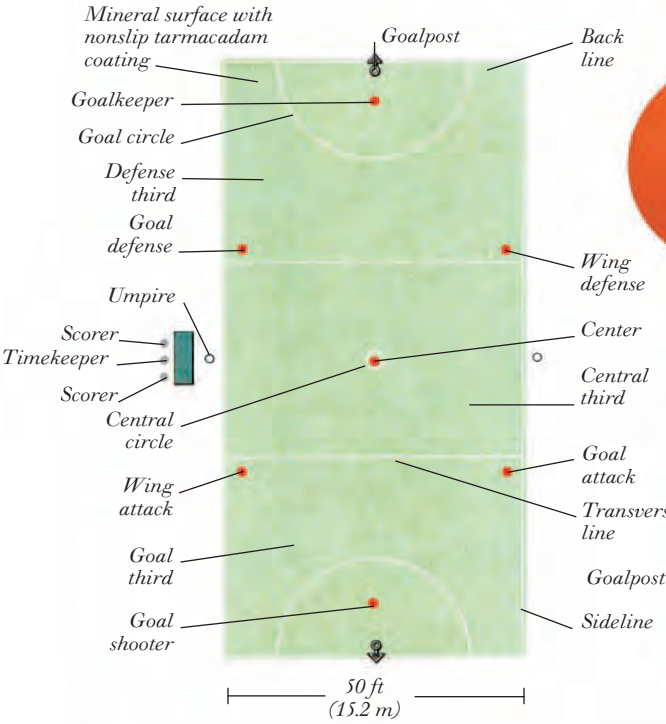


VOLLEYBALL NET

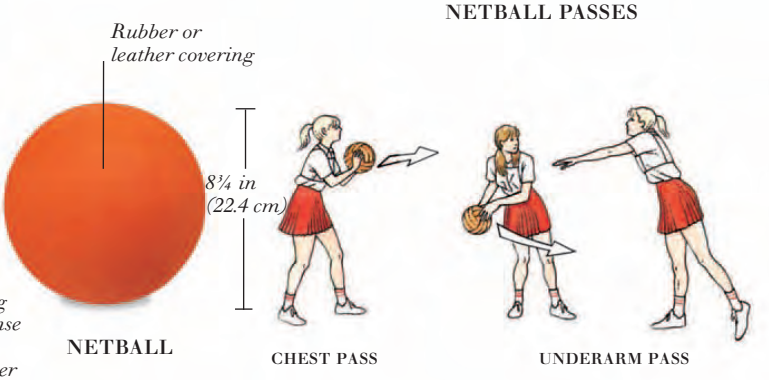


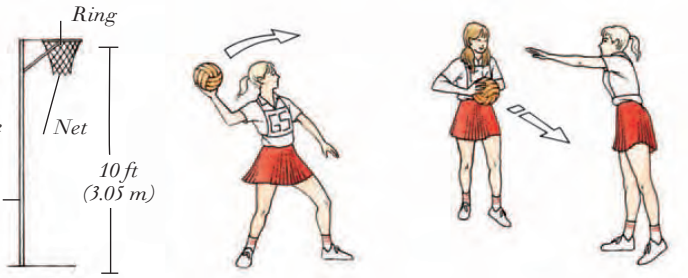
KNEE PADS

NETBALL COURT

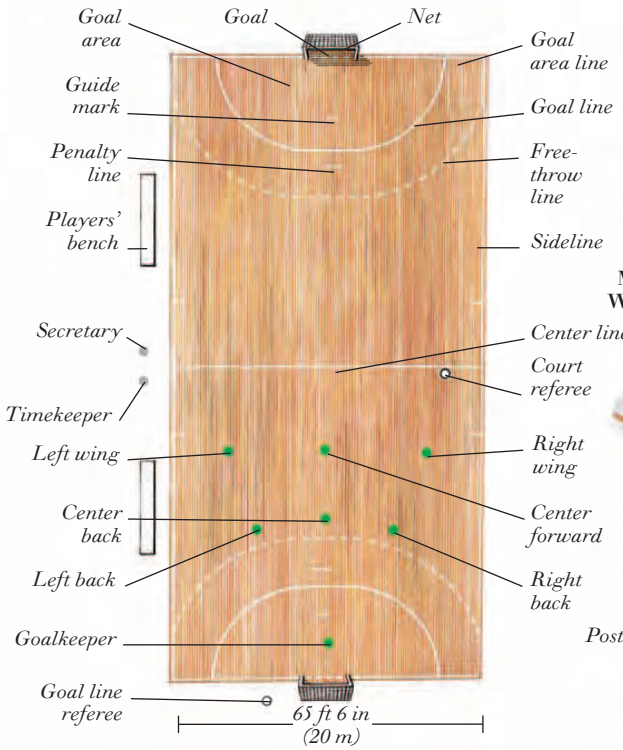


NETBALL PASSES

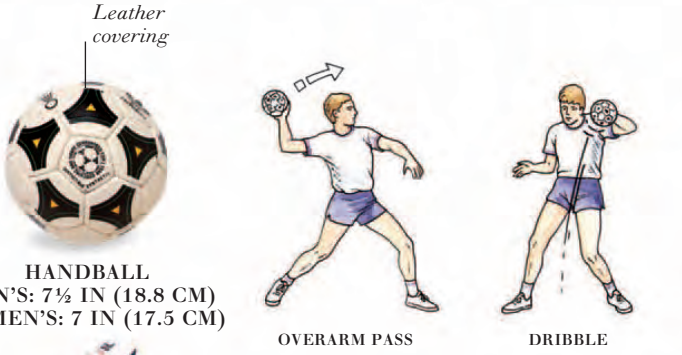


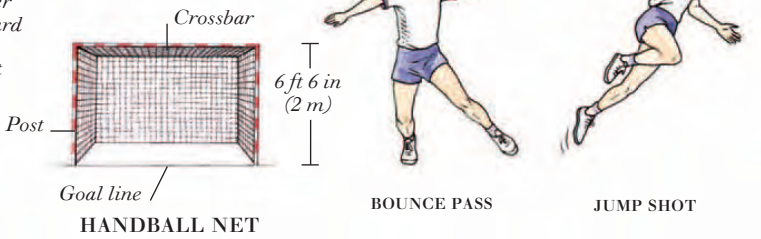


HANDBALL COURT



HANDBALL SKILLS

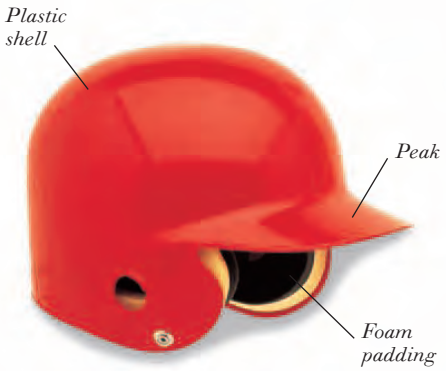




Baseball

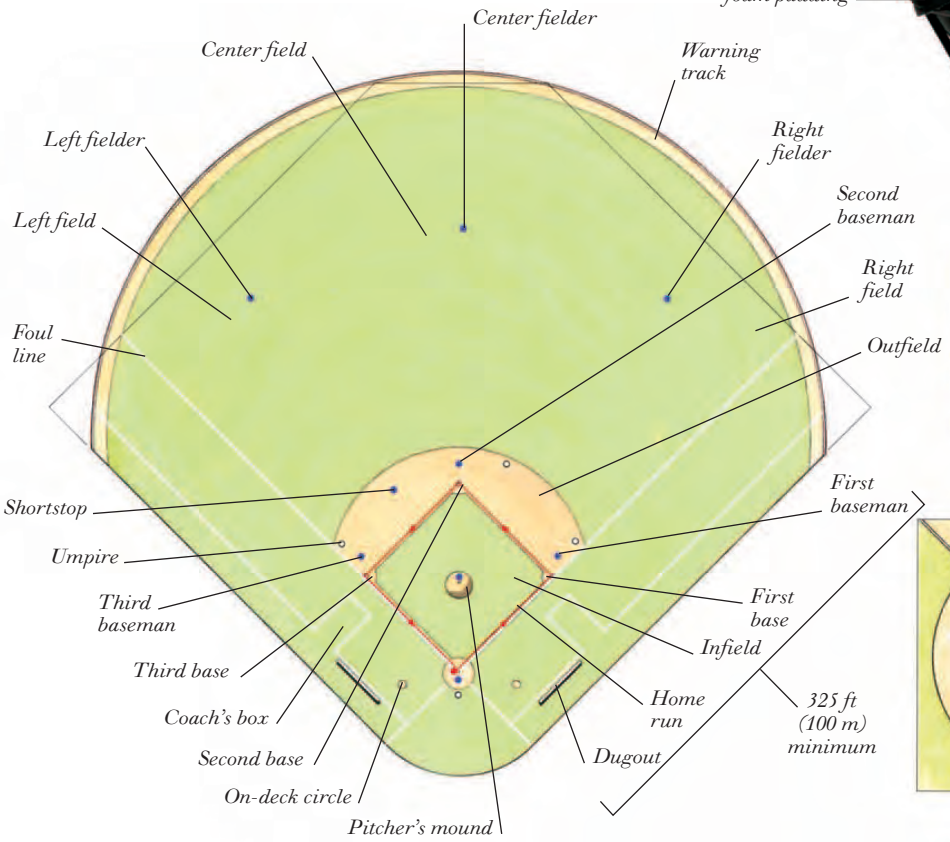
BASEBALL IS A BALL GAME for two teams of nine players. The batter hits the ball thrown by the opposing team's pitcher, into the area between the foul lines. He then runs around all four fixed bases in order to score a run, touching or "tagging" each base in turn. The pitcher must throw the ball at a height between the batter's armpits and knees, a height which is called the "strike zone." A ball pitched in this area that crosses over the "home plate" is called a "strike" and the batter has three strikes in which to try and hit the ball (otherwise he is "struck out"). The fielding team tries to get the batting team out by catching the ball before it bounces, tagging a player of the batting team with the ball who is running between bases, or by tagging a base before the player has reached it. Members of the batting team may stop safely at a base as long as it is not occupied by another member of their team. When the batter runs to first base, his teammate at first base must run on to second—this is called "force play." A game consists of nine innings and each team will bat once during an inning. When three members of the batting team are out, the teams swap roles. The team with the greatest number of runs wins the game.

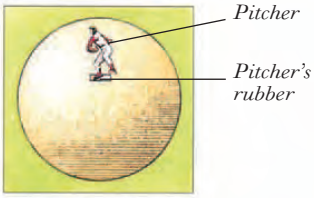
BATTER'S HELMET



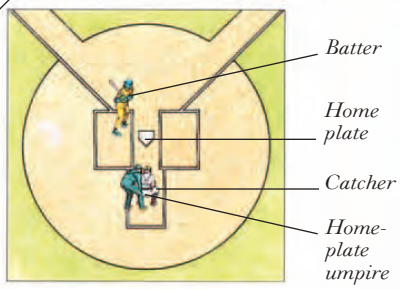
CATCHER'S MASK

BASEBALL FIELD





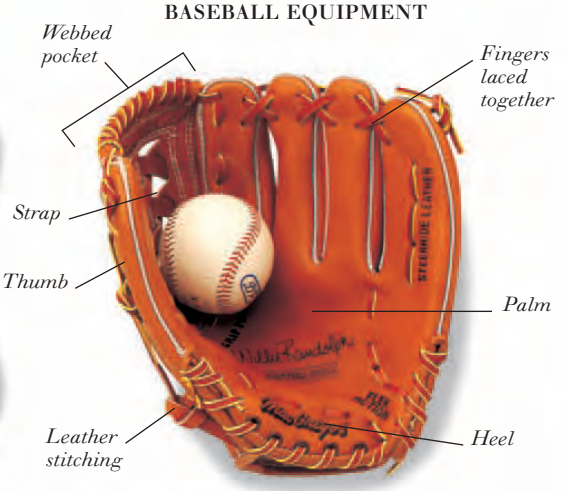
PITCHER'S MOUND



HOME PLATE

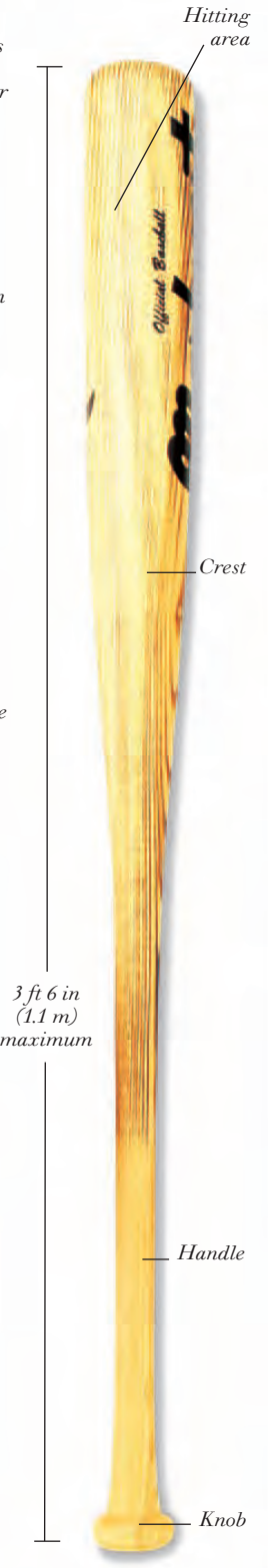
MAKING A BASEBALL

BASEBALL EQUIPMENT



FIELDER'S GLOVE AND BALL

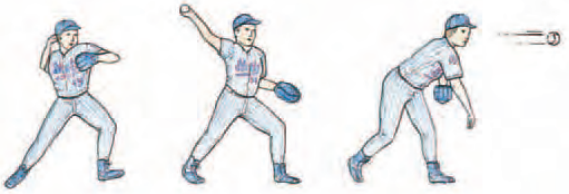
BASEBALL SHOE



BAT

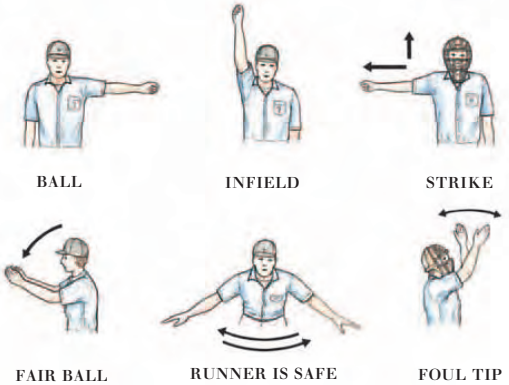
THE PITCHING SEQUENCE

THE WIND-UP 1 | THE WIND-UP 2 | THE WIND-UP 3



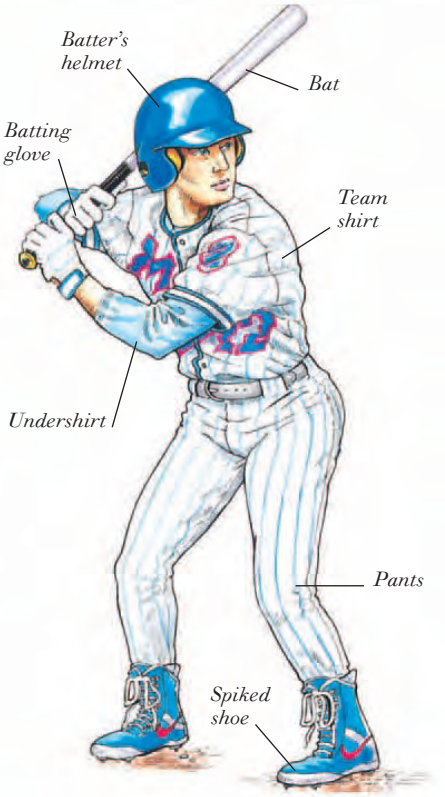
THE WIND-UP 4 | THE RELEASE | THE FOLLOW-THROUGH

UMPIRING SIGNALS



BALL | INFIELD | STRIKE

FAIR BALL | RUNNER IS SAFE | FOUL TIP

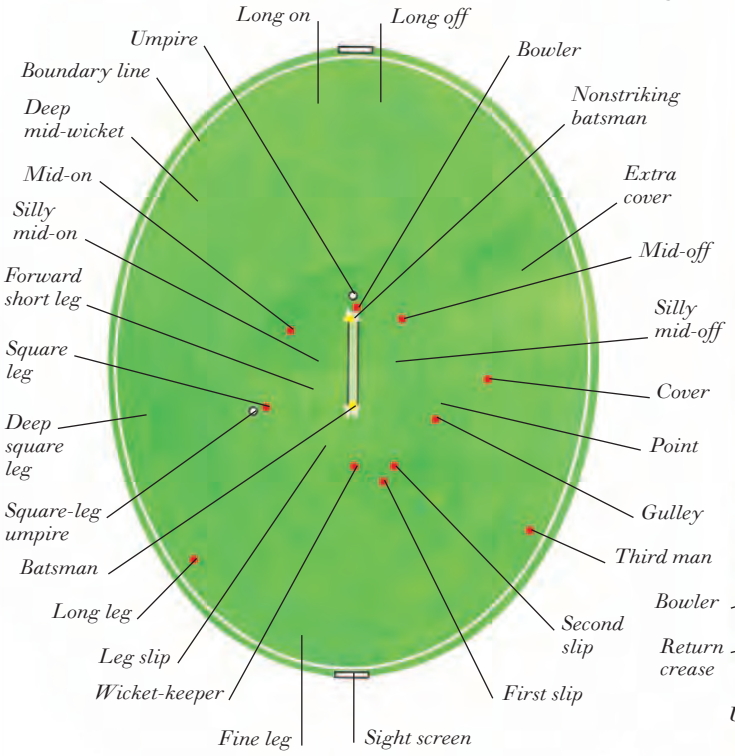


BATTER

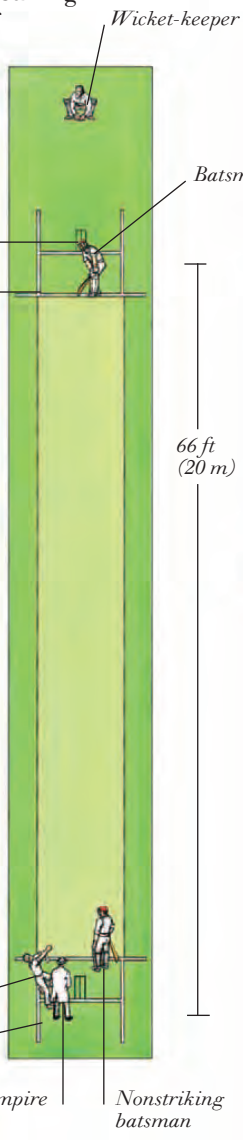
Cricket

CRICKET IS A BALL GAME PLAYED by two teams of eleven players on a pitch with two sets of three stumps (wickets). The bowler bowls the ball down the pitch to the batsman of the opposing team, who must defend the wicket in front of which he stands. The object of the game is to score as many runs as possible. Runs can be scored individually by running the length of the playing strip, or by hitting a ball that lands outside the boundary ("six"), or that lands inside the boundary but bounces or rolls outside ("four"); the opposing team will bowl and field, attempting to dismiss the batsmen. A batsman can be dismissed in one of several ways: by the bowler hitting the wicket with the ball ("bowled"); by a fielder catching the ball hit by the batsman before it touches the ground ("caught"); by the wicket-keeper or another fielder breaking the wicket while the batsman is attempting a run and is therefore out of his ground ("stumped" or "run out"); by the batsman breaking the wicket with his own bat or body ("hit wicket"); by a part of the batsman's body being hit by a ball that would otherwise have hit the wicket ("leg before wicket" ["lbw"]). A match consists of one or two innings and each inning ends when the tenth batsman of the batting team is out, when a certain number of overs (a series of six balls bowled) have been played, or when the captain of the batting team "declares" ending the innings voluntarily.

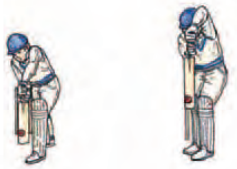
POSSIBLE FIELD POSITIONS FOR AN AWAY SWING BOWLER TO A RIGHT-HANDED BATSMAN (IN RED) AND OTHER FIELD POSITIONS



CRICKET PITCH

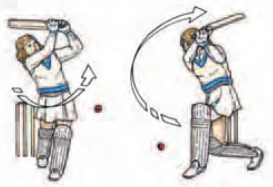


CRICKET STROKES



FORWARD DEFENSIVE STROKE

BACKWARD DEFENSIVE STROKE



ON-DRIVE

OFF-DRIVE

PULL

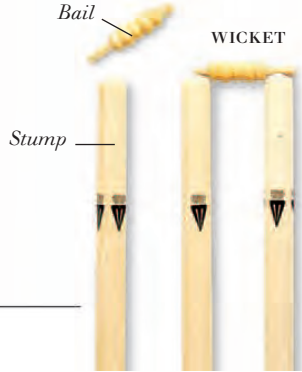
HOOK

SQUARE CUT

LEG GLANCE

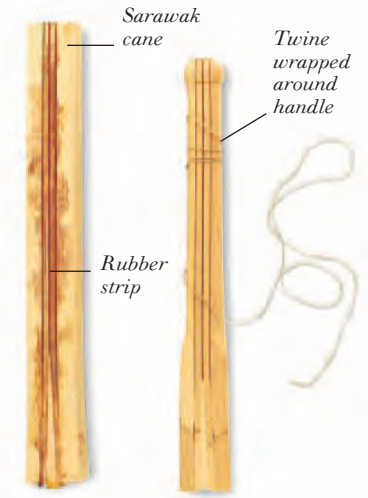
CRICKET BALL AND WICKET

BALL



WICKET

MAKING A BAT HANDLE



LAMINATING THE WOOD

BINDING THE HANDLE

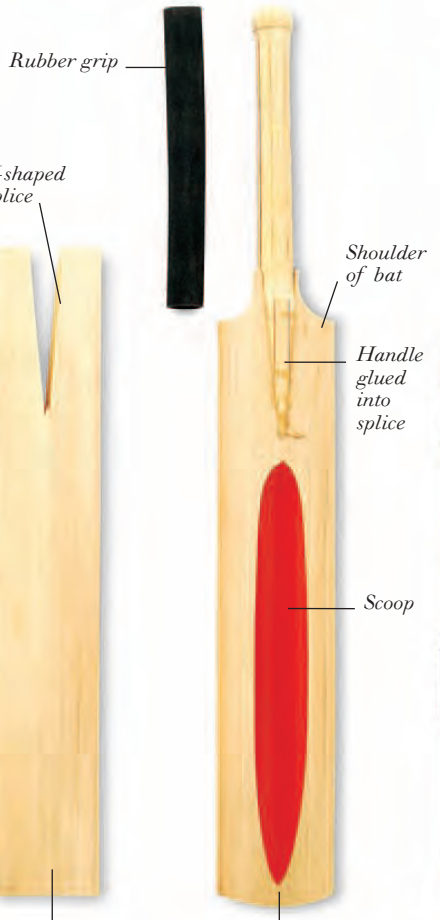
PROTECTIVE CLOTHING

BATTING GLOVE

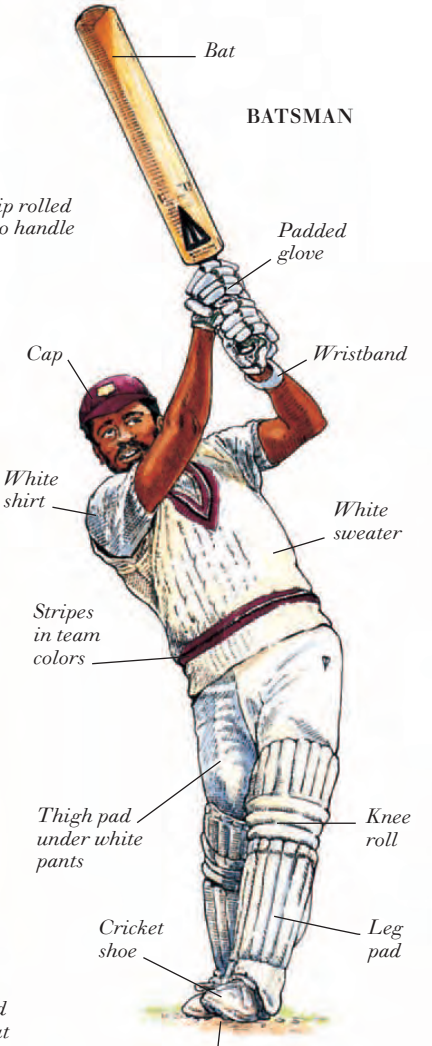
WICKET-KEEPER'S GLOVES

HELMET

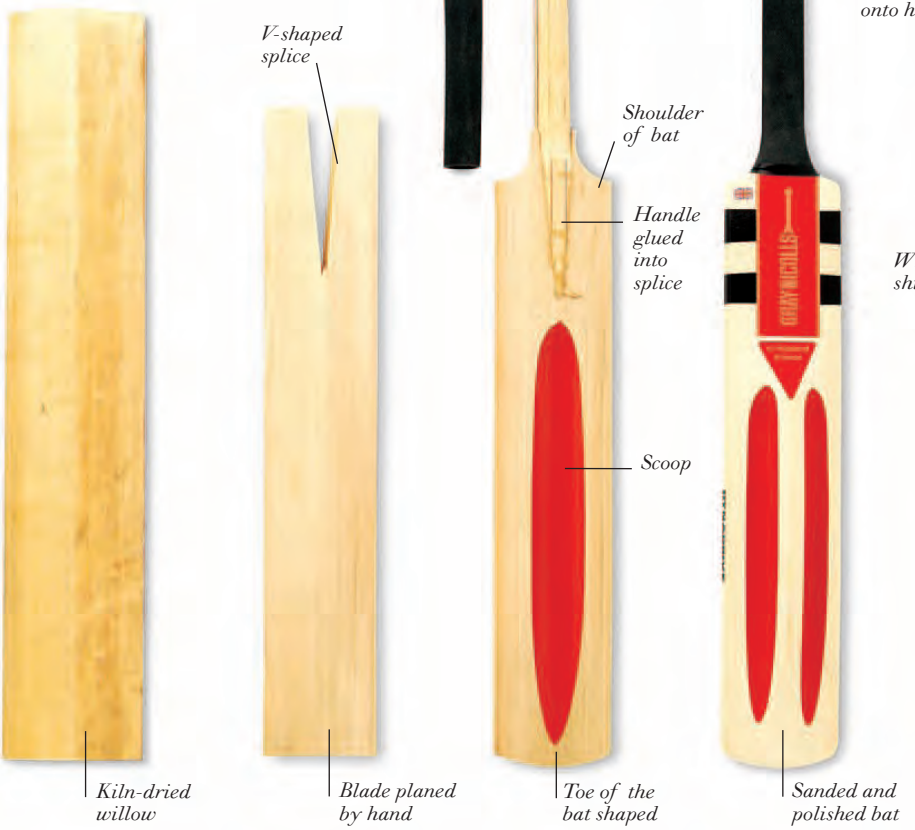
ADDING THE HANDLE TO THE BAT



BATSMAN



MAKING A BAT BLADE



SEASONING THE TIMBER

CUTTING THE SPLICE

FITTING THE HANDLE

FINISHING TOUCHES

Field hockey, lacrosse, and hurling

ALL OVER THE WORLD, TEAM GAMES have evolved that require that a ball be struck or carried, and tossed at the end of a stick. Early forms of these games include hurling, shinty, bandy, and pelota. Field hockey is played by men and women: two teams of 11 players try to gain and keep possession of the ball and score goals by using the hockey stick to propel the ball into their opponents' goal net. Skills such as passing, pushing, or hitting the ball by slapping or lifting it in a flicking movement, and shooting at goal are crucial. Hockey is played indoors and outdoors on grass or synthetic fields. Lacrosse is played internationally as a 12-a-side game for women and as 10-a-side game for men. The women's field has no absolute boundaries but the men's field has clearly defined side-lines and end-lines. The ball is kept in play by being carried, thrown, or batted with the crosse, and rolled or kicked in any direction. In men's and women's lacrosse, play can continue behind the marked goal areas. Similar skills are required in hurling—a Gaelic field game played on the same field as Gaelic football (see pp. 528–529), using the same goalposts and net. In hurling, the ball may be struck with or carried on the hurley and, when off the ground, may be struck with the hand or kicked. Goals (three points) are scored when the ball passes between the posts and under the crossbar; one point is scored when it passes between the posts and over the crossbar.

GOALKEEPER'S EQUIPMENT

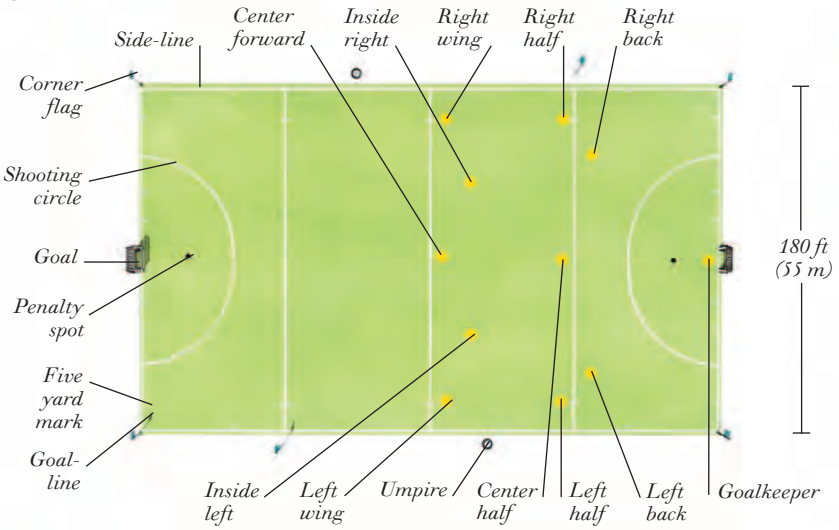
HELMET

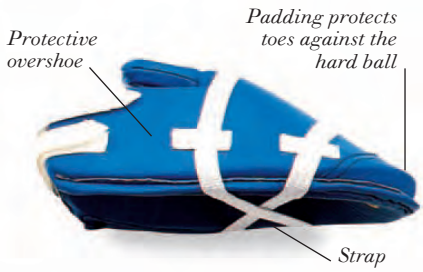
GAUNTLET

HOCKEY STICK AND BALL

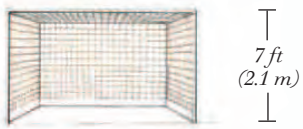
BALL

HOCKEY FIELD



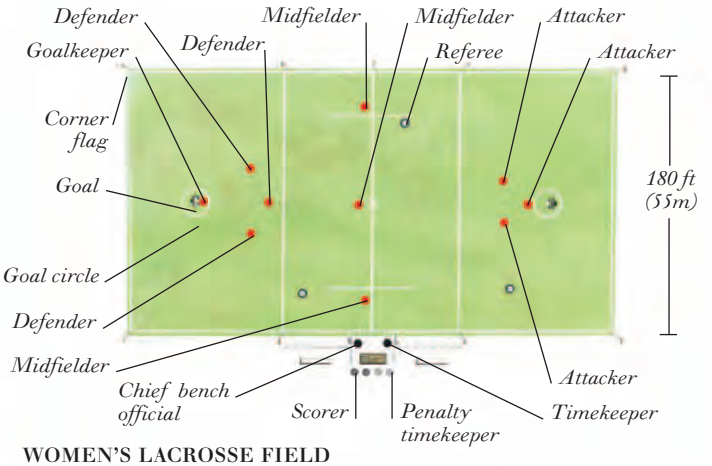


GOALKEEPER'S KICKER

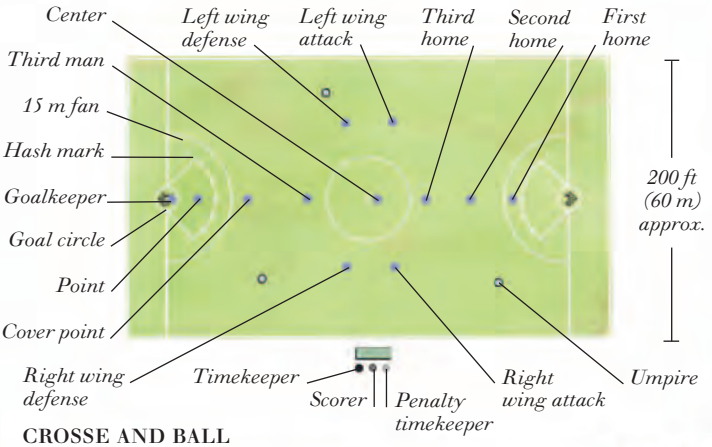


HOCKEY GOAL

MEN'S LACROSSE FIELD



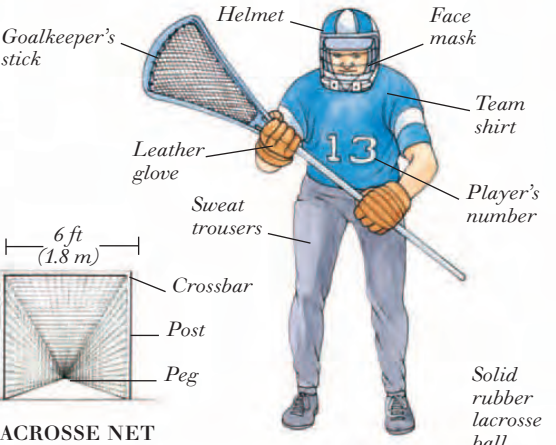
WOMEN'S LACROSSE FIELD



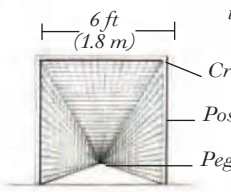
LACROSSE SKILLS

CRADLING THROWING SIDE-SHOOTING

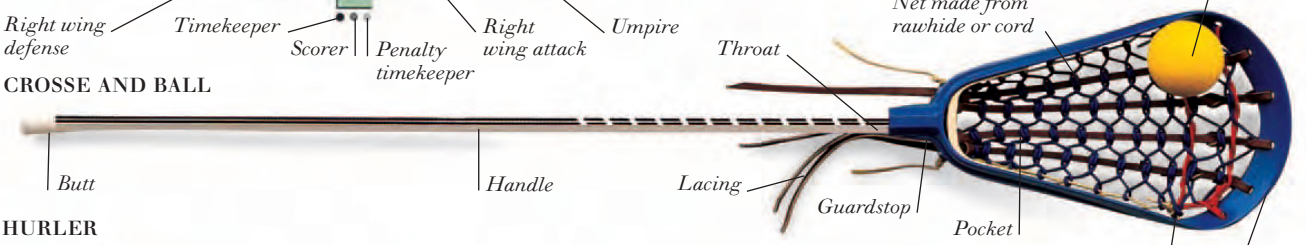
LACROSSE GOALKEEPER



LACROSSE NET

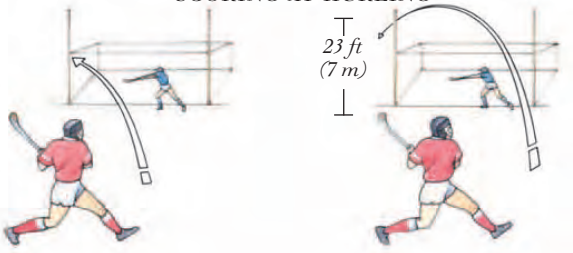


CROSSE AND BALL



HURLER

SCORING AT HURLING



GOAL (3 POINTS) POINT (1 POINT)

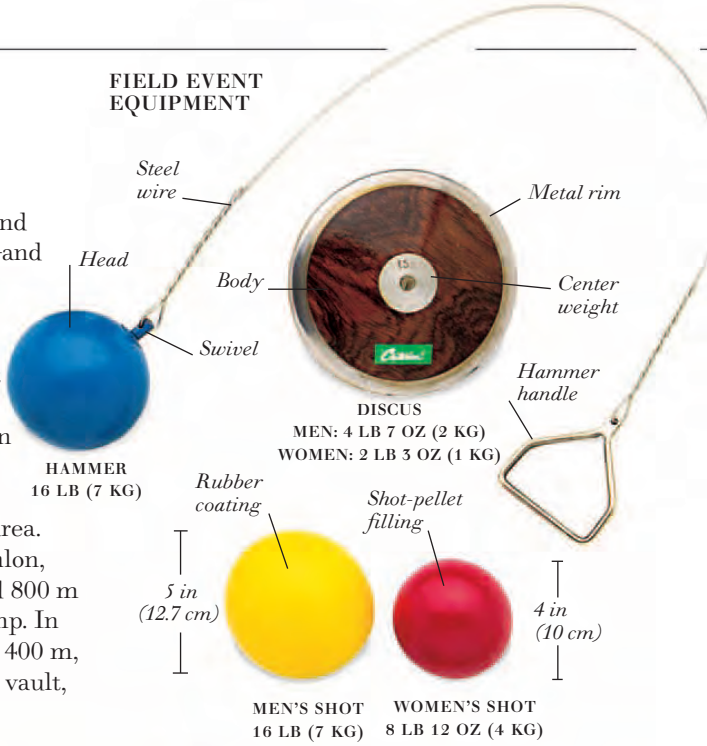
HURLING BALL

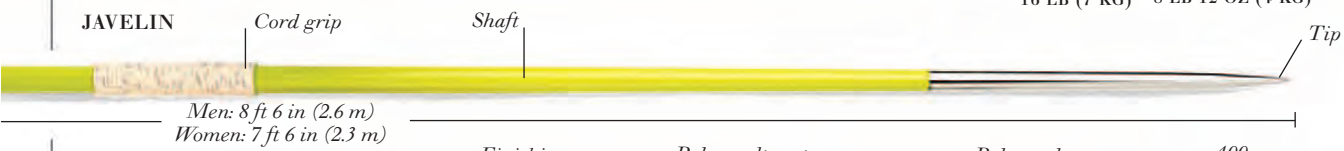
HURLEY AND HURLING BALL

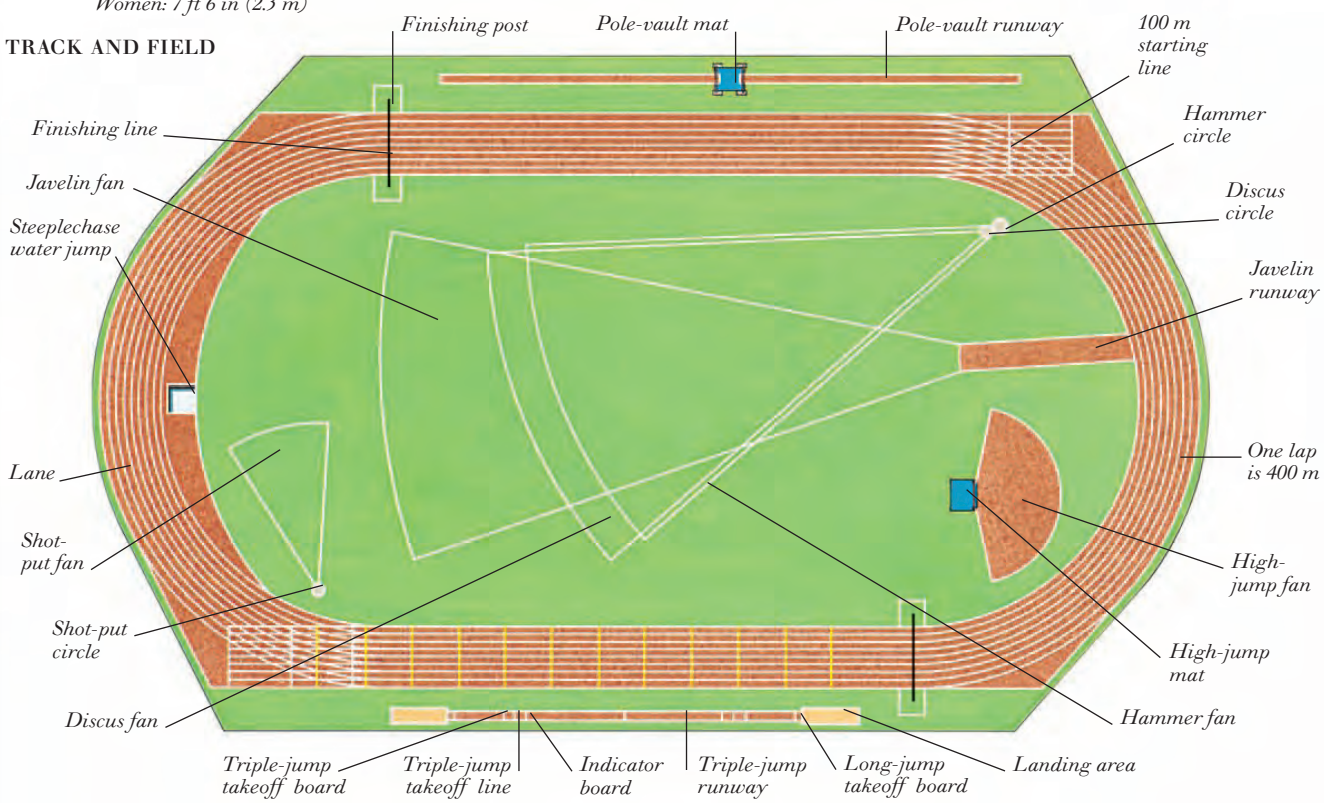
Track and field

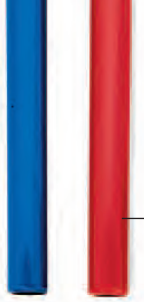
THE SPORTS that make up track and field are divided into two main groups: track events—which include sprinting, middle- and long-distance running, relay running, hurdling, and walking—and field events that require jumping and throwing skills. Contests designed to test the speed, strength, agility, and stamina of athletes were held by the ancient Greeks over 4,000 years ago. However, the abolition of the Olympic Games in 393 AD meant that track and field events were neglected until the revival of large-scale competitions in the mid-nineteenth century. Modern stadia offer areas reserved for the long jump, triple jump, and pole vault usually situated outside the running track. The javelin, shot, hammer, and discus are thrown within the track area. Most athletes specialize in one or two events but, in the heptathlon, women compete in seven events, held over two days: 200 m and 800 m races, 100 m hurdles, javelin, shot put, high jump, and long jump. In the decathlon, men compete in 10 events over two days: 100 m, 400 m, and 1,500 m races, 110 m hurdles, javelin, discus, shot put, pole vault, high jump, and long jump.

FIELD EVENT EQUIPMENT









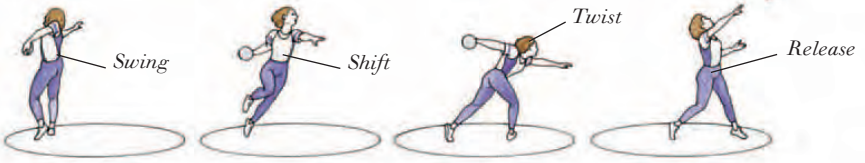
RELAY BATONS

TYPES OF SHOE

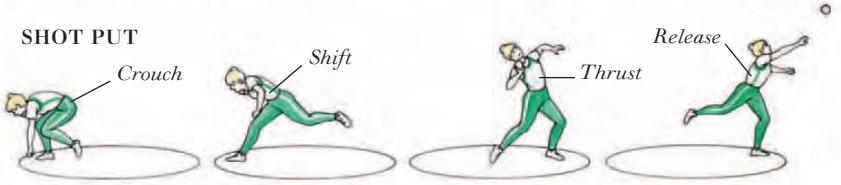
TRACK SHOE

RUNNING SHOE

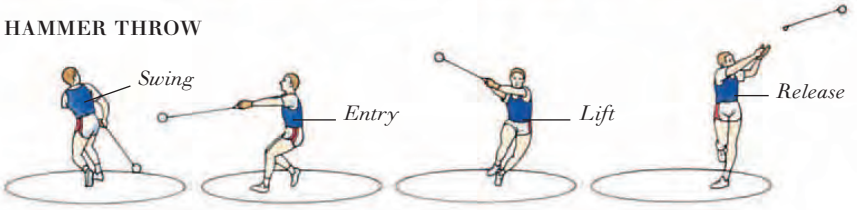
DISCUS THROW

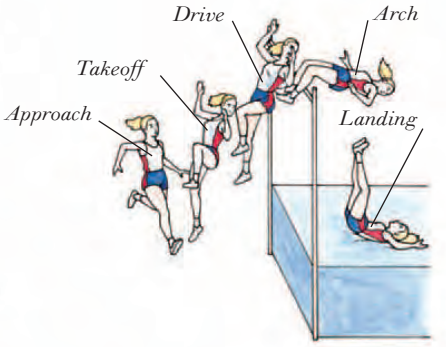


SHOT PUT



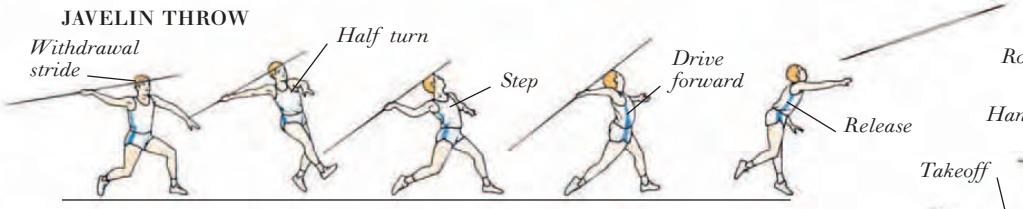
HAMMER THROW



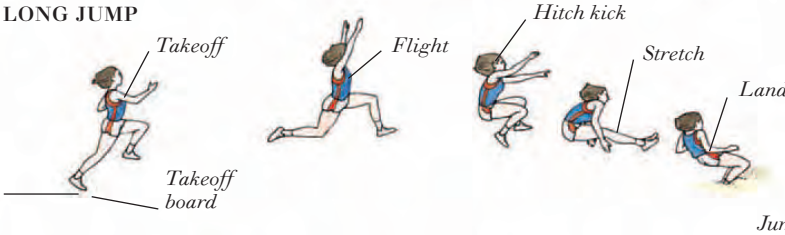


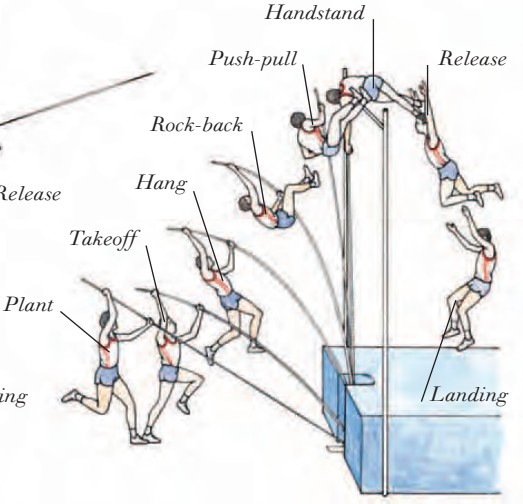
HIGH JUMP

JAVELIN THROW



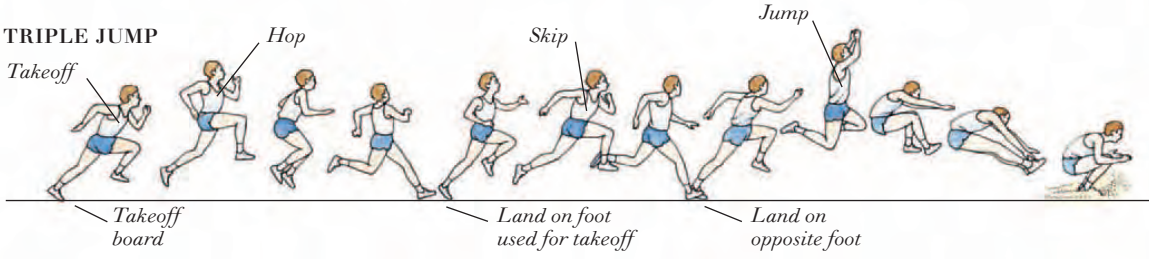
LONG JUMP





POLE VAULT

TRIPLE JUMP



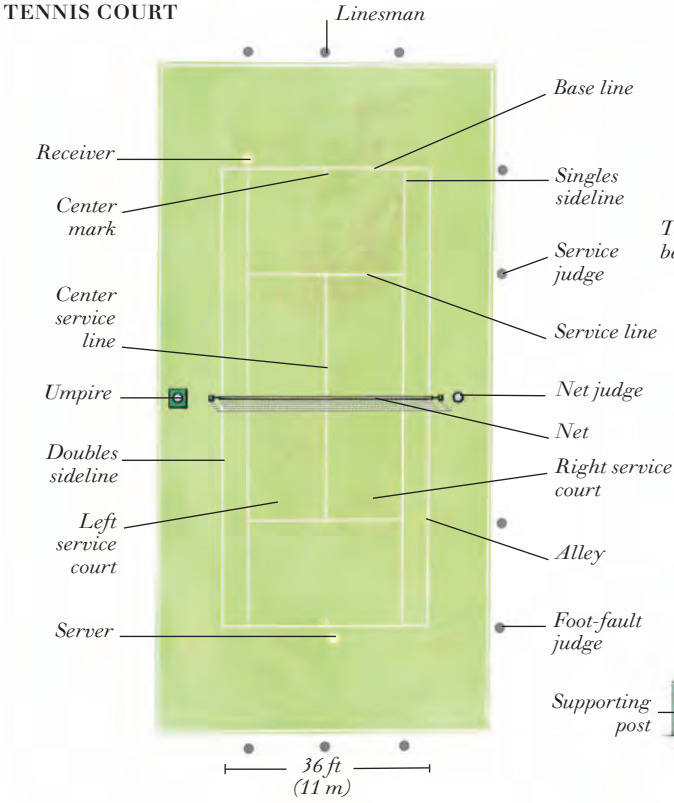
Racket sports

PROTECTIVE EYEWEAR

THE OBJECT OF ALL RACKET SPORTS is to make shots the opponent cannot return. Games are played by two players (singles) or four players (doubles). Racket shape and size is tailored to each sport, but all rackets are constructed of wood, plastic, aluminum, or high-performance materials such as fiberglass and carbon graphite. Racket strings are usually synthetic, although natural gut is still used. Tennis is played on a court divided by a low net. Opposing players serve alternate games. At least six games must be won to gain a set, and two or sometimes three sets are needed to win a match. Tennis courts may be concrete, grass, clay, or synthetic, each surface requiring a different style of play. Badminton is an indoor sport that is played with light, flexible rackets and a birdie on a court with a high net. Players can score points only on their serve. The first to reach 15 points (11 points for women's singles) wins the game. Two games are needed to win a match. Squash and racketball are both played in enclosed courts. One player hits the ball against the front wall, and the other tries to return it before it bounces on the floor more than once. Squash rackets have smaller, rounder heads and stiffer frames than badminton rackets. In the United States, the game is played on a narrower court than an international court using a much harder ball. Squash games are played to 15 points (American) or 9 points (international). In racketball, players use a ball that is larger and bouncier than a squash ball. The racket is thick and sturdy, with a large head, short handle, and a thong that loops around the wrist. Points can be won only when serving, and the first player to reach 21 points wins.

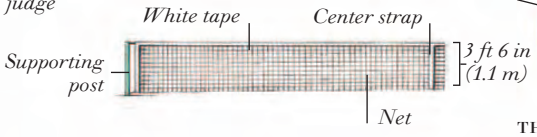
TENNIS RACKET

TENNIS COURT



TENNIS PLAYER

TENNIS NET

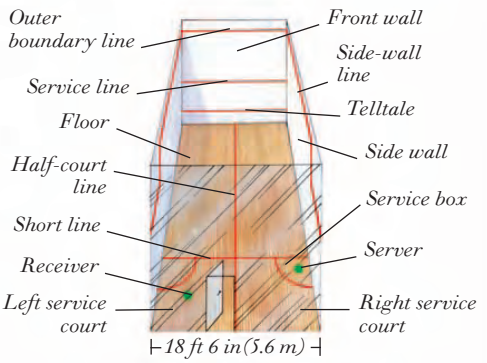


MAKING A TENNIS BALL

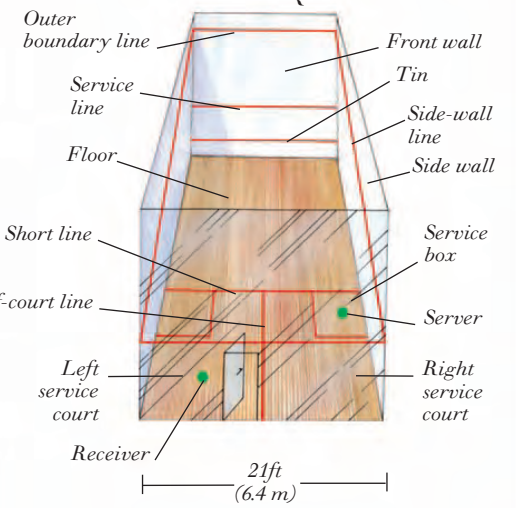
BADMINTON RACKET AND BIRDIE

SQUASH RACKET AND SQUASH BALLS

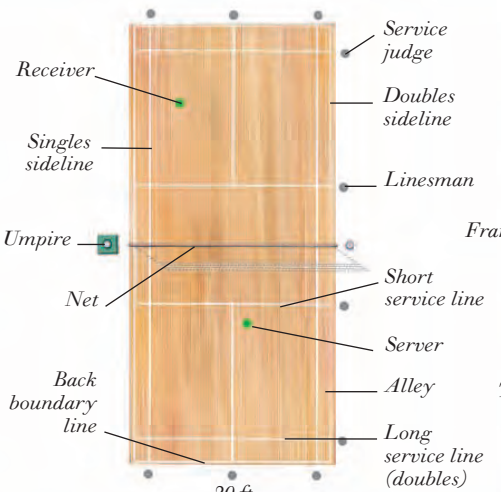
AMERICAN SQUASH COURT



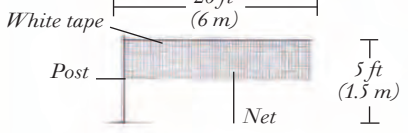
INTERNATIONAL SQUASH COURT



BADMINTON COURT

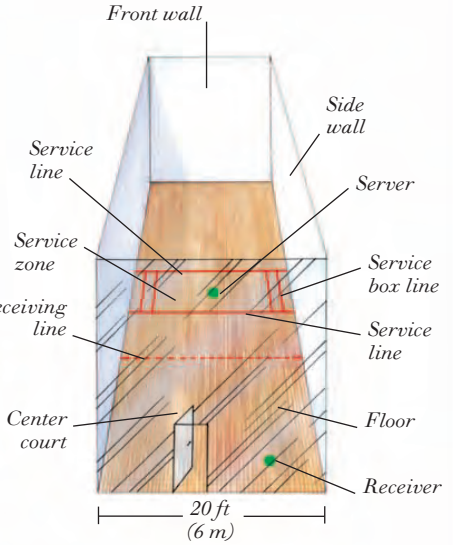


BADMINTON NET



RACKETBALL RACKET, BALL, AND GLOVE

RACKETBALL COURT

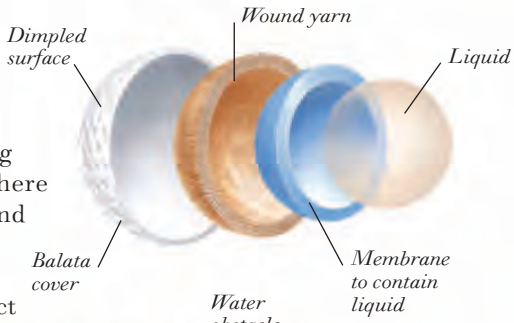


Golf

GOLF BALL AND TEE

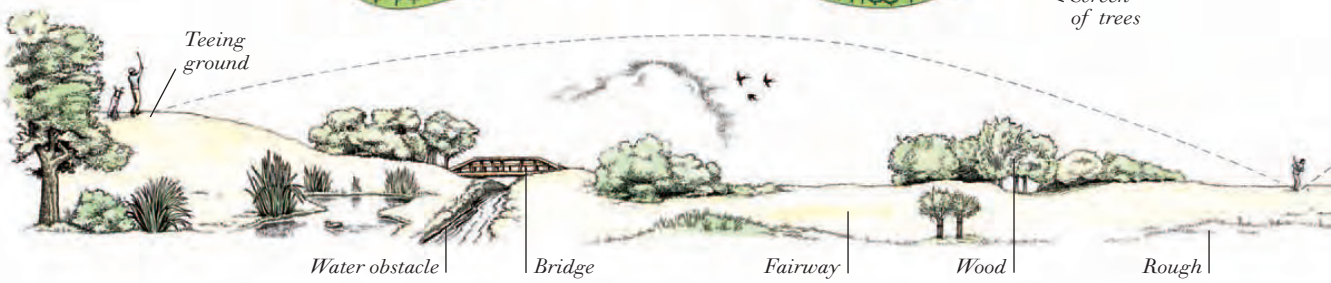
THE GAME OF GOLF was first played in Scotland some 400 years ago. Players are required to hit a ball, using a wooden or iron club, from a smooth level point or "teeing ground," down the "fairway," and on to a putting green where the target hole is located. The fairway is a strip of clear land along which there are natural hazards—such as ponds and streams, man-made hazards—such as bunkers (sand pits), and rough (areas of uncut grass). Championship golf courses have 18 holes. The object of the game is to hit the ball into each hole in turn, and to complete the "round" using as few strokes as possible. Players compete individually or in teams, playing the course together in groups of two, three, or four. The two basic forms of competition are match play and stroke play. In match play, the side winning the majority of holes over a certain number of rounds wins the match. In stroke play, the winner is the player who finishes a certain number of rounds having made the fewest strokes.

GOLF BALL WITH BALATA SURFACE

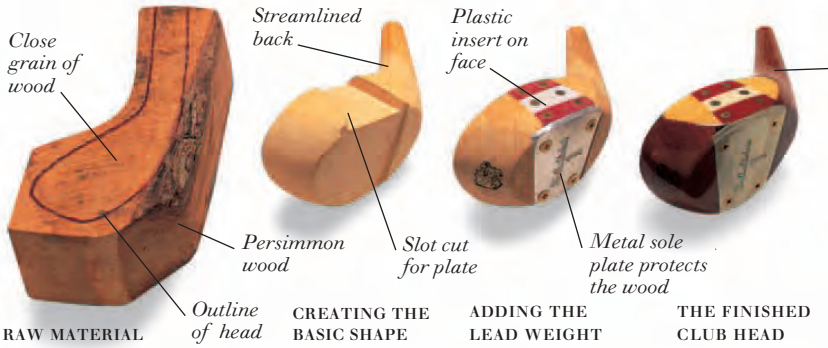


AUGUSTA NATIONAL GOLF COURSE, AUGUSTA, GEORGIA, US

A TYPICAL HOLE

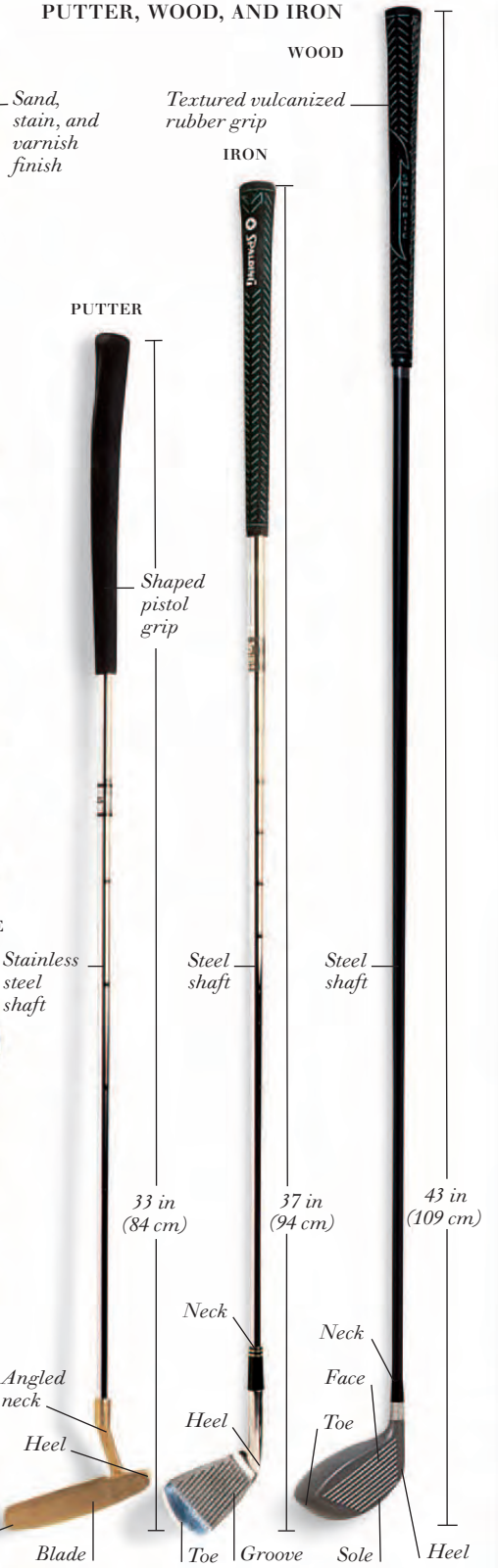


Making a wooden club

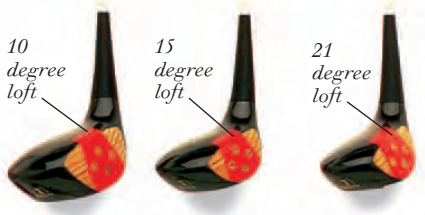


RAW MATERIAL | CREATING THE BASIC SHAPE | ADDING THE LEAD WEIGHT | THE FINISHED CLUB HEAD

Putter, wood, and iron

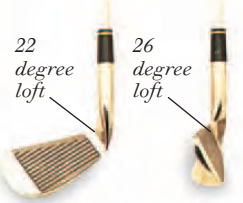


Range of wooden clubs

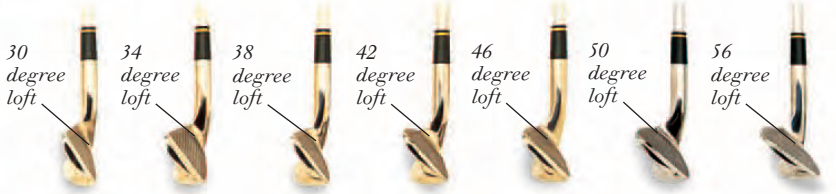


DRIVER | 3-WOOD | 5-WOOD

Range of iron clubs



3-IRON | 4-IRON



5-IRON | 6-IRON | 7-IRON | 8-IRON | 9-IRON | PITCHING WEDGE | SAND WEDGE

Golf accessories

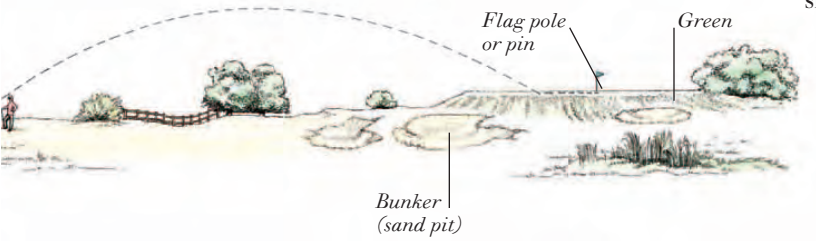
SCORE CARD AND PENCIL

BALL MARKERS | TEES

PITCHMARK REPAIRER

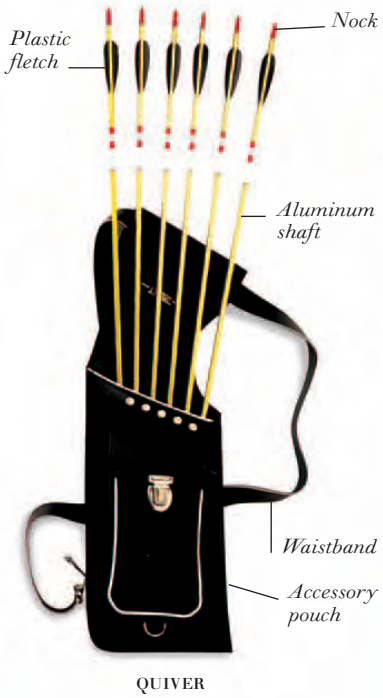
PRACTICE BALL

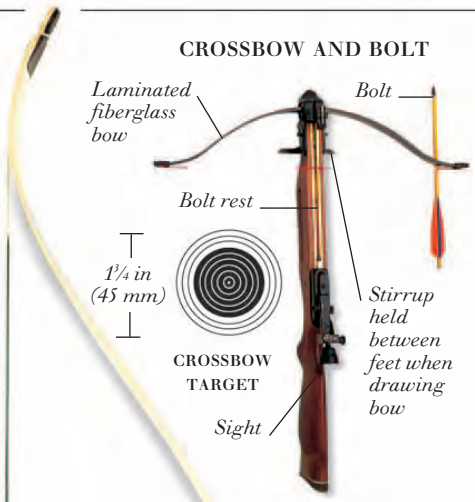
LIGHTWEIGHT SHOE



Archery and shooting

TARGET SHOOTING AND ARCHERY EVOLVED as practice for hunting and battle skills. Modern bows, although designed according to the principles of early hunting bows, use laminates, fiberglass, dacron, and carbon, and are equipped with sights and stabilizers. Competitors in target archery shoot over distances of 100 ft (30 m), 165 ft (50 m), 230 ft (70 m), and 300 ft (90 m) for men, and 100 ft (30 m), 165 ft (50 m), 200 ft (60 m), and 230 ft (70 m) for women. The closer the shot is to the center of the target, the higher the score. The individual scores are added up, and the archer with the highest total wins the competition. Crossbows are used in match competitions over 33 ft (10 m), and 100 ft (30 m). Rifle shooting is divided into three categories: smallbore, bigbore, and air rifle. Contests take place over a variety of distances and further subdivisions are based on the type of shooting position used: prone, kneeling, or standing. The Olympic biathlon combines cross-country skiing and rifle shooting over a course of approximately 12½ miles (20 km). Additional magazines of ammunition are carried in the butt of the rifles. Bigbore rifles fitted with a telescopic sight can be used for hunting and running game target shooting. Pistol shooting events, using rapid-fire pistols, target pistols, and air pistols, take place over 33 ft (10 m), 82 ft (25 m), and 165 ft (50 m) distances. In rapid-fire pistol shooting, a total of 60 shots are fired from a distance of 83 ft (25 m).



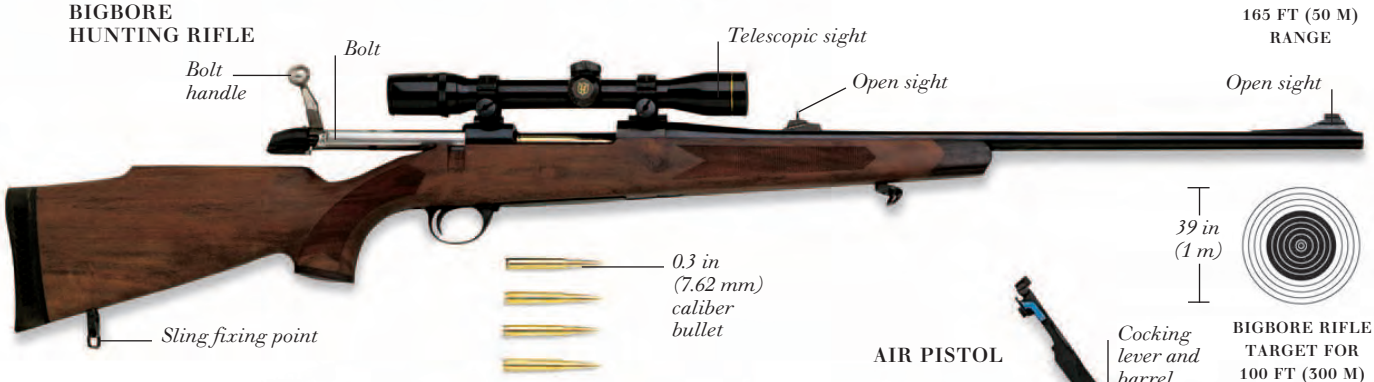


ARCHERY EQUIPMENT

SMALLBORE BIATHLON RIFLE

SMALLBORE FREE RIFLE TARGET FOR 165 FT (50 M) RANGE

BIGBORE HUNTING RIFLE



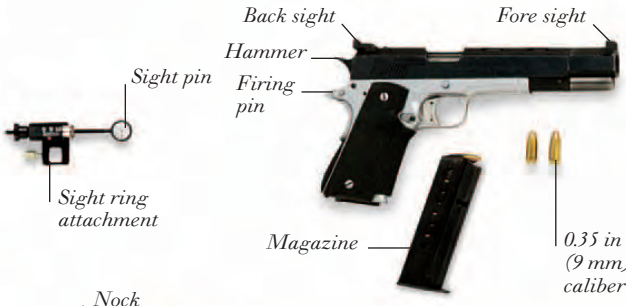
BIGBORE RIFLE TARGET FOR 100 FT (300 M) RANGE

AIR PISTOL

6 in (155 mm)

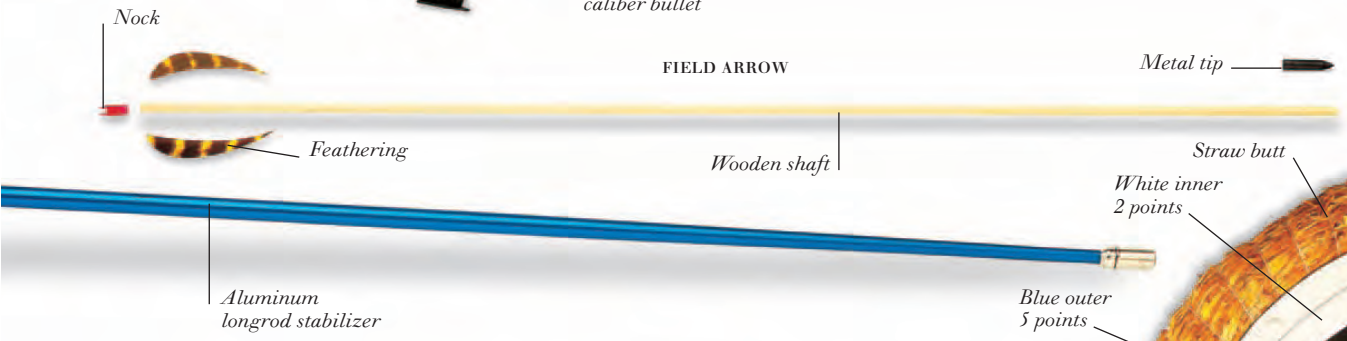
AIR-PISTOL TARGET FOR 33 FT (10 M) RANGE

TARGET PISTOL



PISTOL TARGET FOR 60 FT (18 M) RANGE

FIELD ARROW

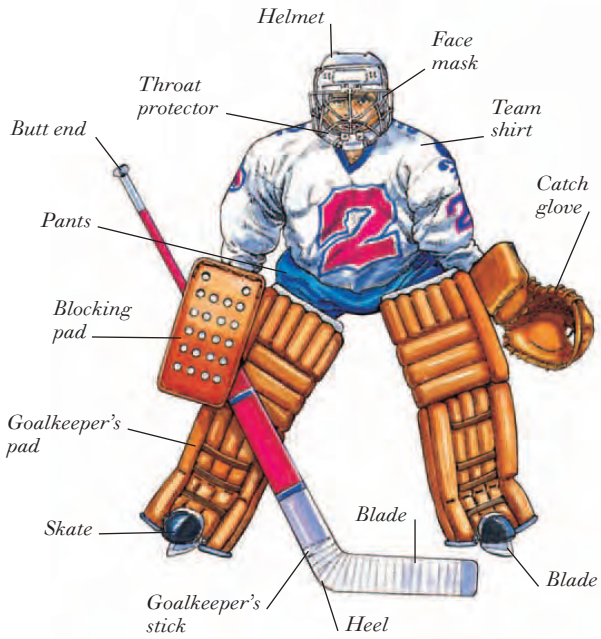


ARCHERY TARGET

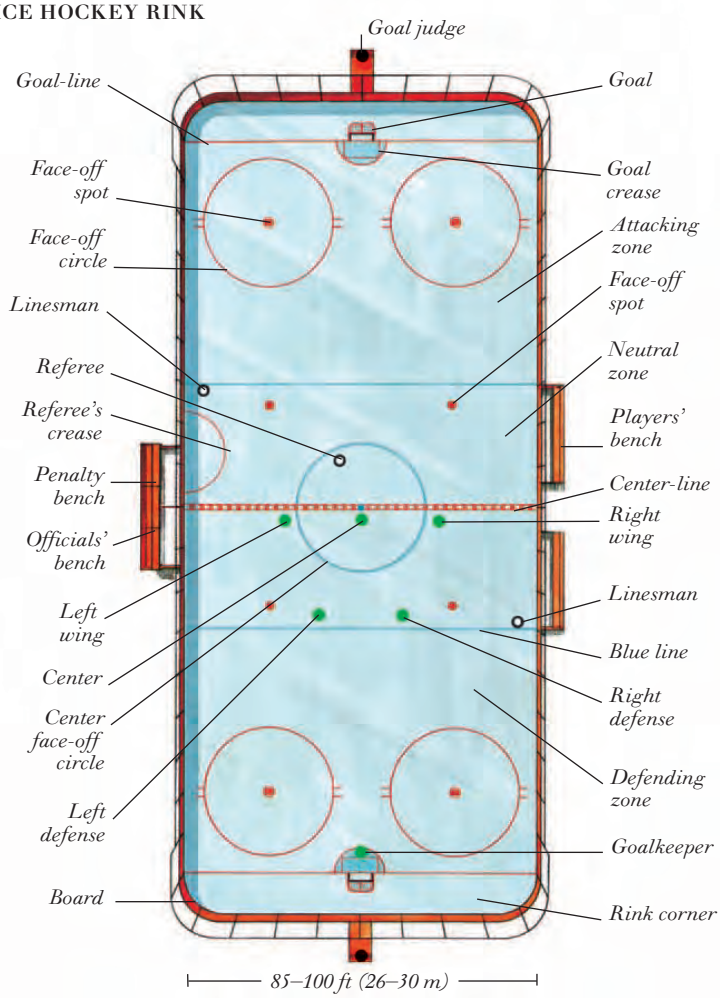
Ice hockey

ICE HOCKEY IS PLAYED by two teams of six players on an ice rink, with a goal net at each end. The object of this fast, and often dangerous, game is to hit a frozen rubber puck into the opposing team's net with a ice hockey stick. The game begins when the referee drops the puck between the sticks of two players from opposing teams, who "face off." The rink is divided into three areas: defending, neutral, and attacking zones. Players may move with the puck and pass the puck to one another along the ice, but may not pass it more than two zones across the rink markings. A goal is scored when the puck entirely crosses the goal-line between the posts and under the crossbar of the goal. A team may field up to 20 players although only six players are allowed on the ice at one time; substitutions occur frequently. Each game consists of three periods of 20 minutes, divided by breaks of 15 minutes.

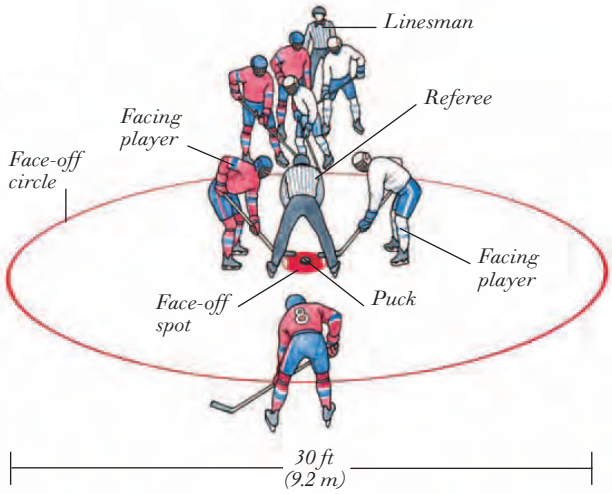
GOALKEEPER

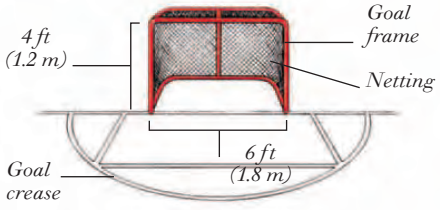


ICE HOCKEY RINK

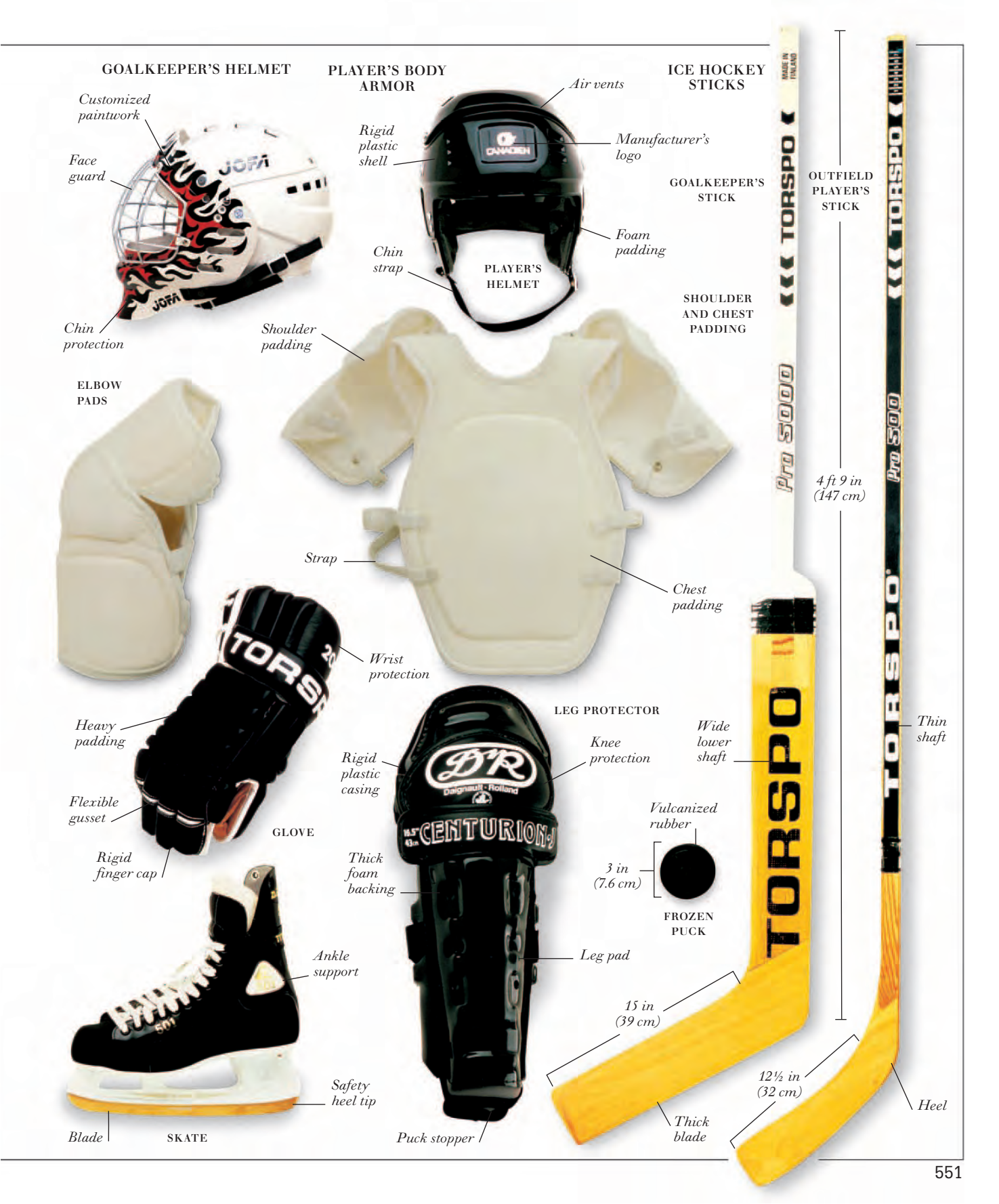


THE FACE OFF





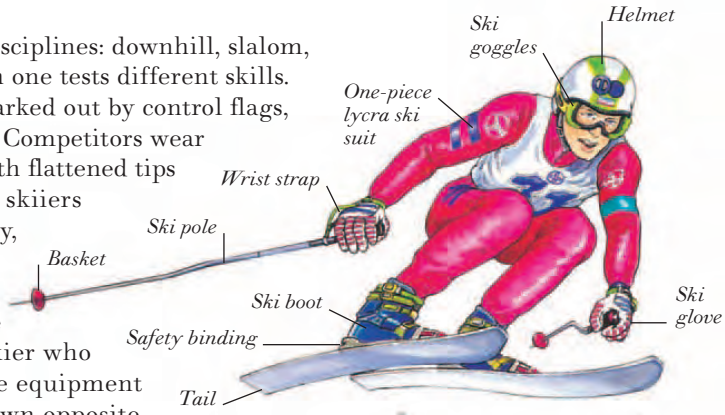
ICE HOCKEY GOAL


GOALKEEPER'S HELMET
Customized paintwork
Face guard
Chin protection
PLAYER'S BODY ARMOR
Air vents
Rigid plastic shell
Manufacturer's logo
Foam padding
Chin strap
PLAYER'S HELMET
ICE HOCKEY STICKS
GOALKEEPER'S STICK
OUTFIELD PLAYER'S STICK
SHOULDER AND CHEST PADDING
Shoulder padding
ELBOW PADS
Strap
Chest padding
Wrist protection
Heavy padding
Flexible gusset
Rigid finger cap
GLOVE
LEG PROTECTOR
Rigid plastic casing
Knee protection
Thick foam backing
Leg pad
Vulcanized rubber
3 in (7.6 cm)
FROZEN PUCK
Wide lower shaft
Thin shaft
4 ft 9 in (147 cm)
15 in (39 cm)
12½ in (32 cm)
Thick blade
Heel
Ankle support
Safety heel tip
Blade
SKATE
Puck stopper
TORSPO
Pro 5000

Alpine skiing

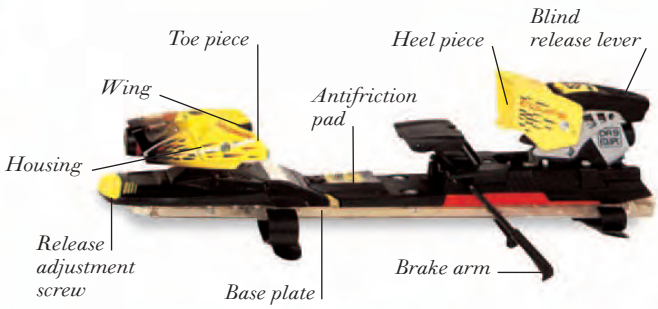
COMPETITIVE ALPINE SKIING is divided into four disciplines: downhill, slalom, giant slalom, and super-giant slalom (Super-G). Each one tests different skills. In downhill skiing, competitors race down a slope marked out by control flags, known as "gates," and are timed on a single run only. Competitors wear crash helmets, one-piece Lycra suits, and long skis with flattened tips to minimize air resistance. Slalom and giant slalom skiiers negotiate a twisting course requiring balance, agility, and quick reactions. Courses are defined by pairs of gates. Racers must pass through each pair of gates to complete the course successfully. Competitors are timed on two runs over different courses, and the skier who completes the courses in the shortest time wins. The equipment and protective guards used by slalom skiiers are shown opposite. In Super-G races, competitors ski a single run that combines the technical challenge of slalom with the speed of downhill. The course requires skiers to complete medium-to-long radius turns at high speed, and contain up to two jumps. Clothing is the same as for downhill, but slightly shorter skis are used.

DOWNHILL SKIER



ALPINE SKI SLOPE COURSES

SKI BOOT



SAFETY BINDING

SLALOM CLOTHING AND EQUIPMENT

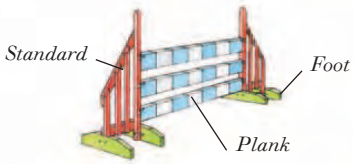
Equestrian sports

EQUESTRIAN SPORTS HAVE TAKEN place throughout the world for centuries: events involving mounted horses were recorded in the Olympic Games of 642 BC. Showjumping, however, is a much more recent innovation, and the first competitions were held at the beginning of the 1900s. In this sport, horse and rider must negotiate a course of variable, unfixed obstacles, making as few mistakes as possible. Showjumping fences consist of wooden stands, known as standards or wings, that support planks or poles. Parts of the fence are designed to collapse on impact, preventing injury to the horse and rider. Judges penalize competitors for errors, such as knocking down obstacles, refusing jumps, or deviating from the course. Depending on the type of competition, the rider with the fewest faults, most points, or fastest time wins. There are two basic forms of horse racing—flat races and races with jumps, such as steeplechase or hurdle races. Thoroughbred horses are used in this sport, since they have great strength and stamina and can achieve speeds of up to 40 mph (65 kph). Jockeys wear "silks"—caps and jackets designed in distinctive colors and patterns that help identify the horses. In harness racing, the horse is driven from a light, two-wheeled carriage called a sulky. Horses are trained to trot and to pace, and different races are held for each of these types of gait. In pacing races, the horses wear hobbles to prevent them from breaking into a trot or gallop. Breeds such as the Standardbred and the French Trotter have been developed especially for this sport.

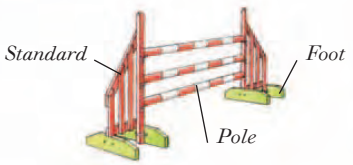
SHOWJUMPING HORSE WITH RIDER

SHOWJUMPING SADDLE

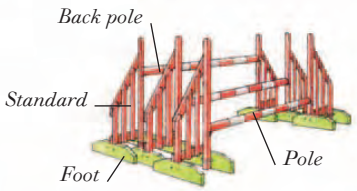
SHOWJUMPING FENCES



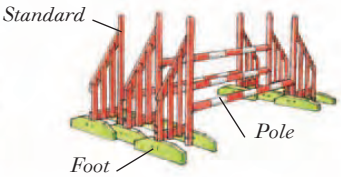
UPRIGHT PLANKS



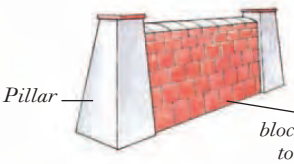
UPRIGHT POLES



TRIPLE BAR (STAIRCASE)

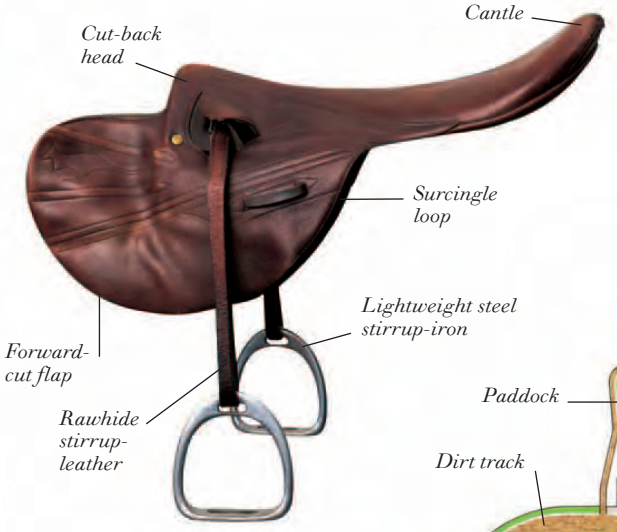


HOG'S-BACK

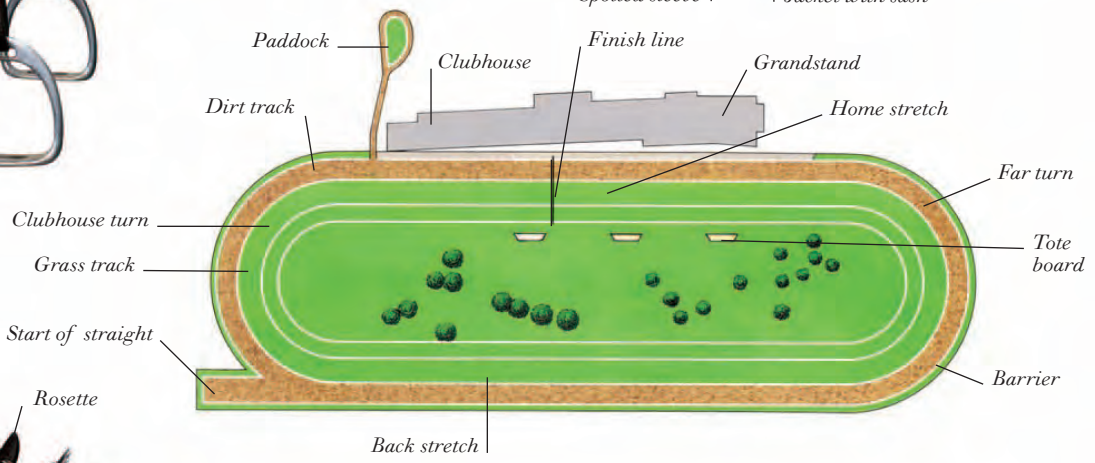


WALL

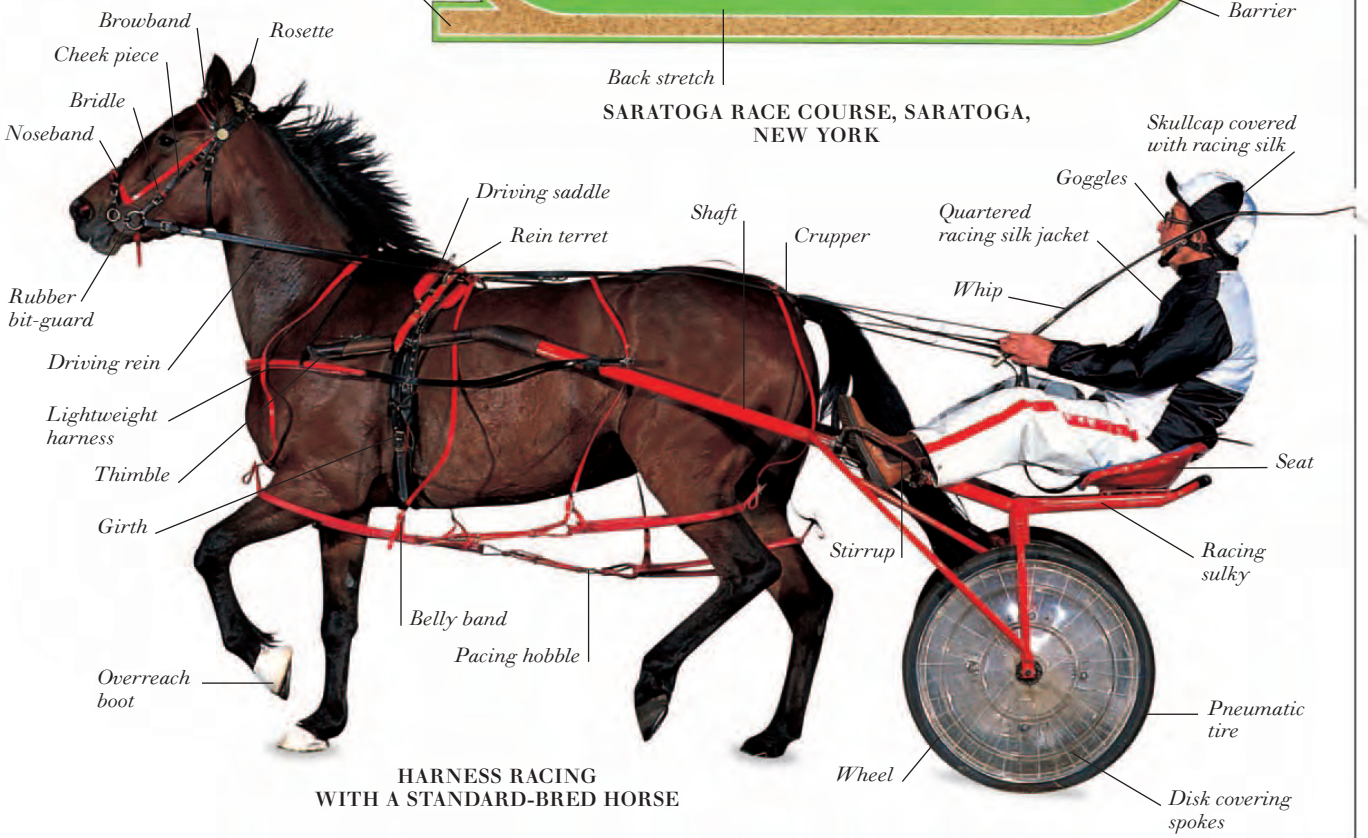
RACING SADDLE



RACING SILKS



SARATOGA RACE COURSE, SARATOGA, NEW YORK



HARNESS RACING
WITH A STANDARD-BRED HORSE

Judo and fencing

COMBAT SPORTS ARE BASED ON THE SKILLS used in fighting. In these sports, the competitors may be unarmed—as in judo and boxing—or armed—as in fencing and kendo. Judo is a system of unarmed combat developed in the East. Translated from the Japanese, the name means "the gentle way." Students learn how to turn an opponent's force to their own advantage. The usual costume is loose white pants and a jacket, fastened with a cloth belt. The color of belt indicates the student's level of expertise, from white-belted novices to the expert "black belts." Competitions take place on a mat or "shiaijo," 30 or 33 ft (9 or 10 m) square in size, bounded by "danger" and "safety" areas to prevent injury. Competitors try to throw, pin, or master their opponent by applying pressure to the arm joints or neck. Judo bouts are strictly monitored, and competitors receive points for superior technique, not for injuring their opponent. Fencing is a combat sport using swords, which takes place on a narrow "piste" 46 ft (14 m) long. Competitors try to touch specific target areas on their opponent with their sword or "foil" while avoiding being touched themselves. The winner is the one who scores the greatest number of hits. Fencers wear clothing made from strong white material that affords maximum protection while allowing freedom of movement, steel mesh masks with padded bibs to protect the fencer's neck, and a long white glove on their sword hand. Fencing foils do not have sharpened blades, and their tips end in a blunt button to prevent injuries. Three types of swords are used—foils, épées, and sabers. Official foil and épée competitions always use an electric scoring system. The sword tips are connected to lights by a long wire that passes underneath each fencer's jacket. A bulb flashes when a hit is made.

JUDO HOLDS AND THROWS

SIDE FOUR QUARTER HOLD

SINGLE WING

BODY DROP

ONE ARM SHOULDER THROW

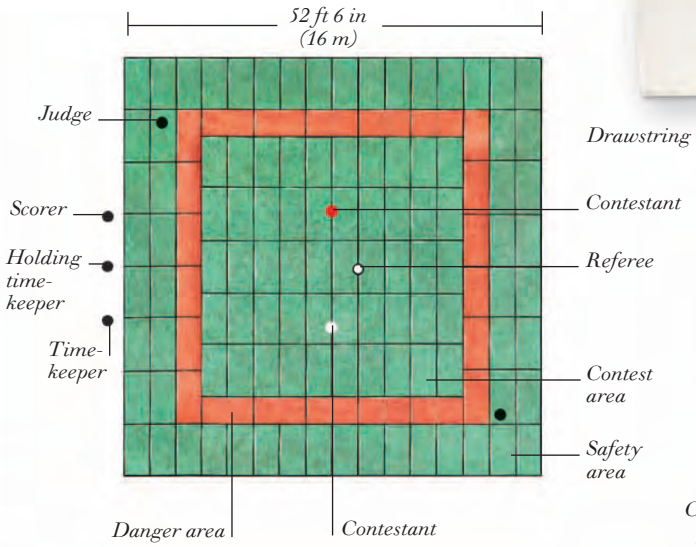
SHOULDER WHEEL

SWEEPING LOW THROW

STOMACH THROW

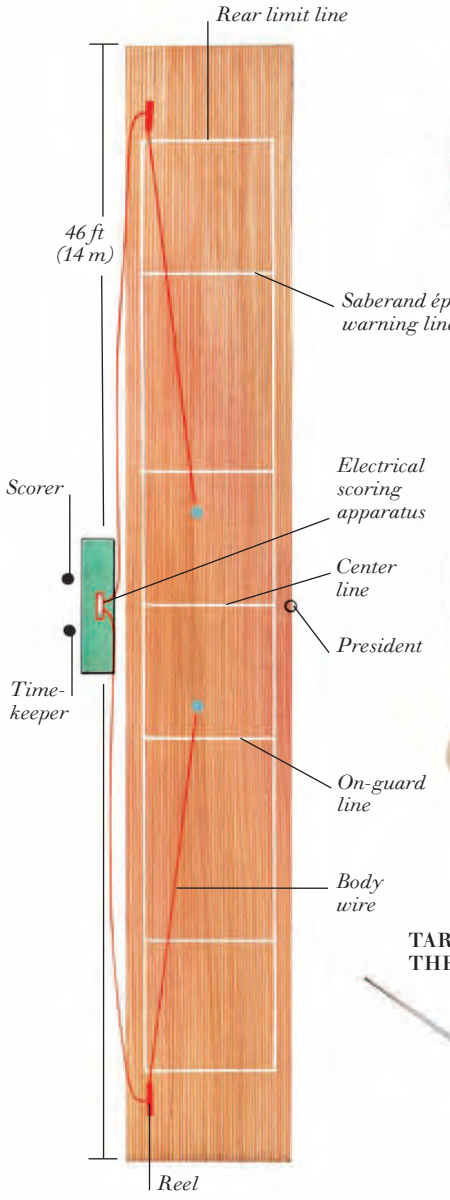
KNEE WHEEL

JUDO MAT

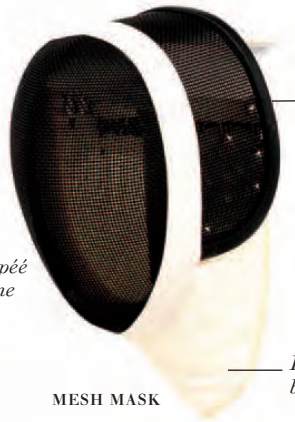


UNIFORM

FENCING PISTE



FENCING EQUIPMENT



MESH MASK

THE SABER

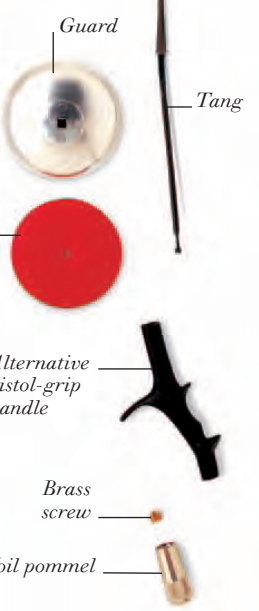
THE FOIL

THE EPEE

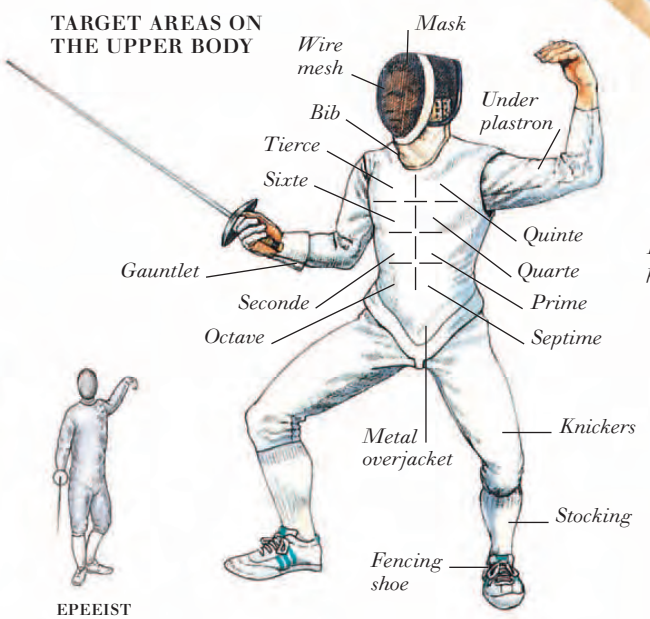
METAL JACKET

GAUNTLET

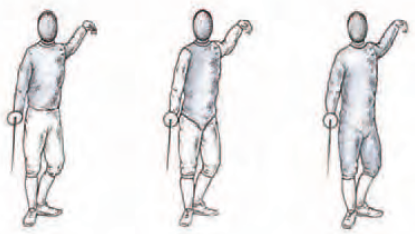
PARTS OF THE SWORD



TARGET AREAS ON THE UPPER BODY



FENCING TARGET AREAS



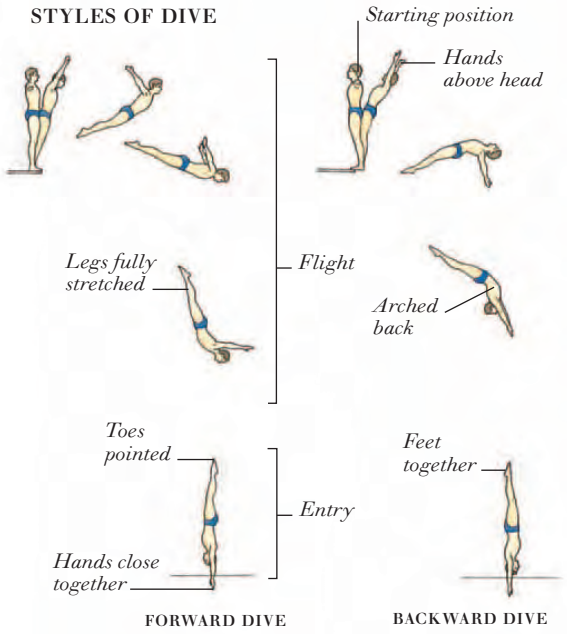
SABREUR FOILIST EPEEIST

Swimming and diving

SWIMMING GOGGLES

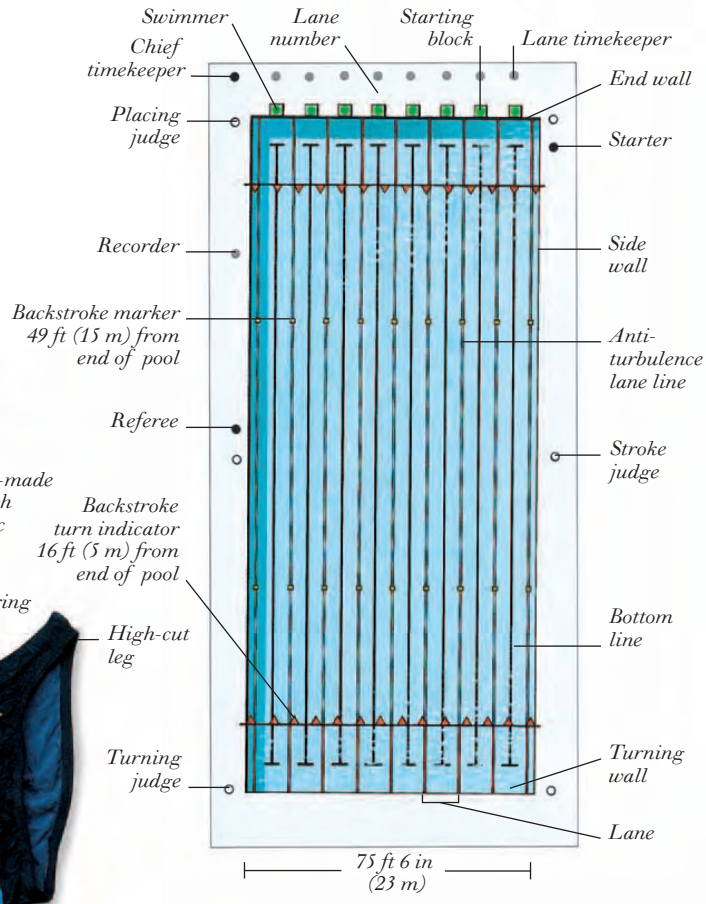
SWIMMING WAS INCLUDED in the first modern Olympic Games in 1896 and diving events were added in 1904. Swimming is both an individual and a team sport and races take place over a predetermined distance in one of the four major categories of stroke—freestyle (usually front crawl), butterfly, breaststroke, and backstroke. Competition pools are clearly marked for racing and antiturbulence lane lines are used to separate the swimmers and help keep the water calm. The first team or individual to finish the race is the winner. Competitive diving is divided into men's and women's springboard and platform (highboard) events. There are six official groups of dives: forward dives, backward dives, armstand dives, twist dives, reverse dives, and inward dives. Competitors perform a set number of dives and after each one a panel of judges award marks according to the quality of execution and the degree of difficulty.

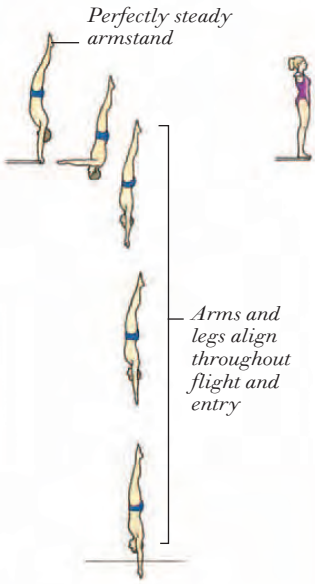
STYLES OF DIVE



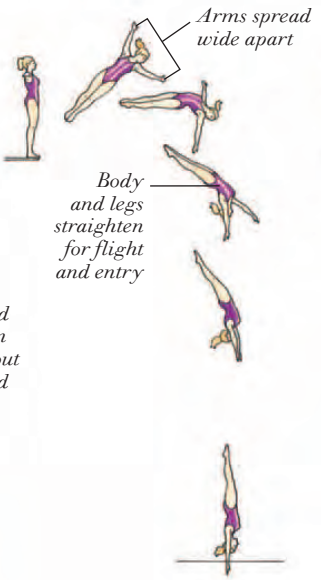
SWIMWEAR

SWIMMING POOL

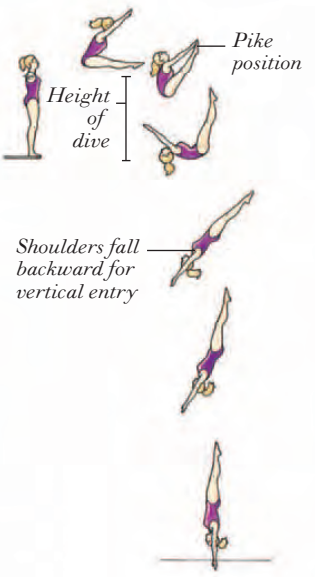




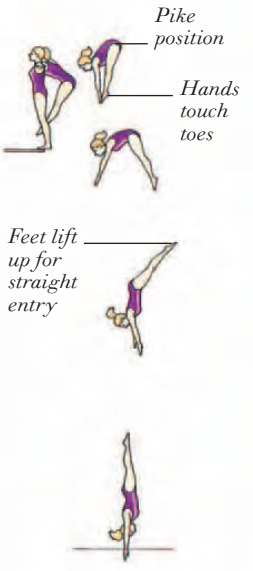
ARMSTAND DIVE



TWIST DIVE



REVERSE DIVE PIKED



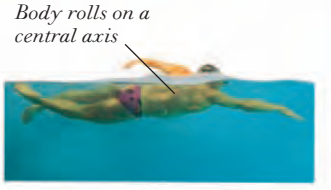
INWARD DIVE PIKED

FRONT CRAWL

FULL BODY STRETCH

LOWER ARM PULL

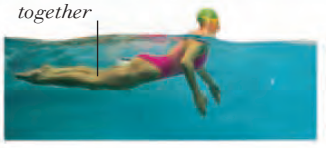
STREAMLINED ARM ENTRY



SIDE-TO-SIDE BODY ROLL

BREASTSTROKE

BODY GLIDE



DOUBLE ARM PULL

SQUEEZING THE WATER

FROG KICK

BACKSTROKE

BODY ROLL

PULLING THROUGH

STRAIGHTENING OUT

SHOULDER LIFT

BUTTERFLY

CATCHING THE WATER

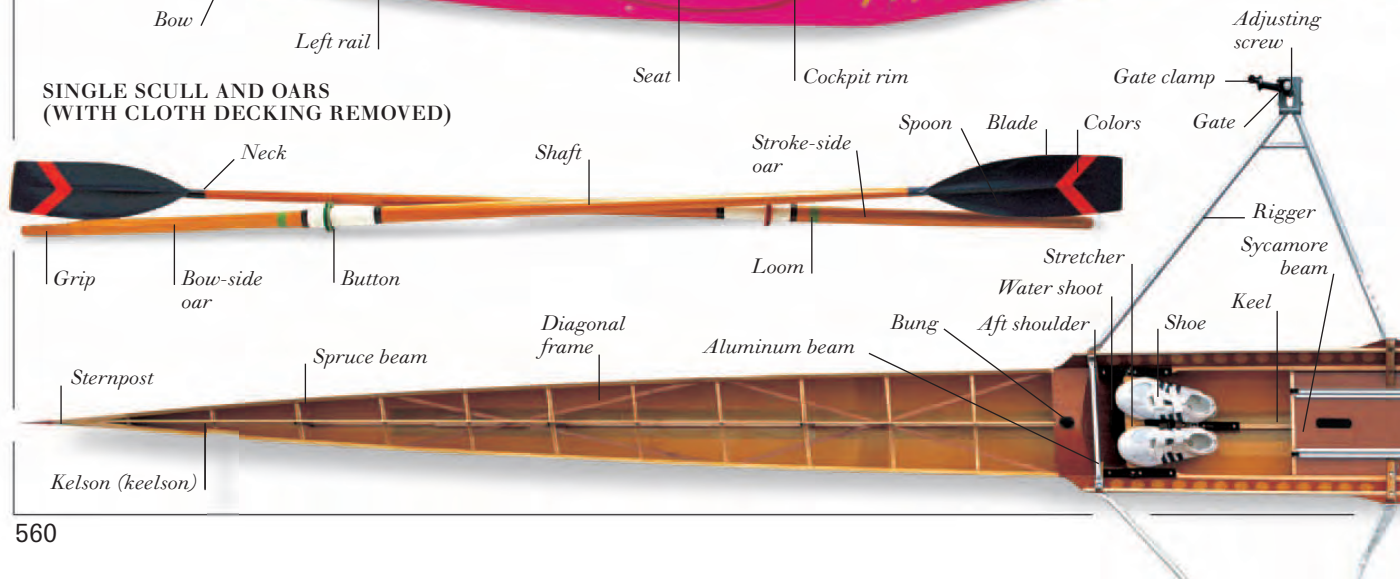
DOUBLE ARM PULL

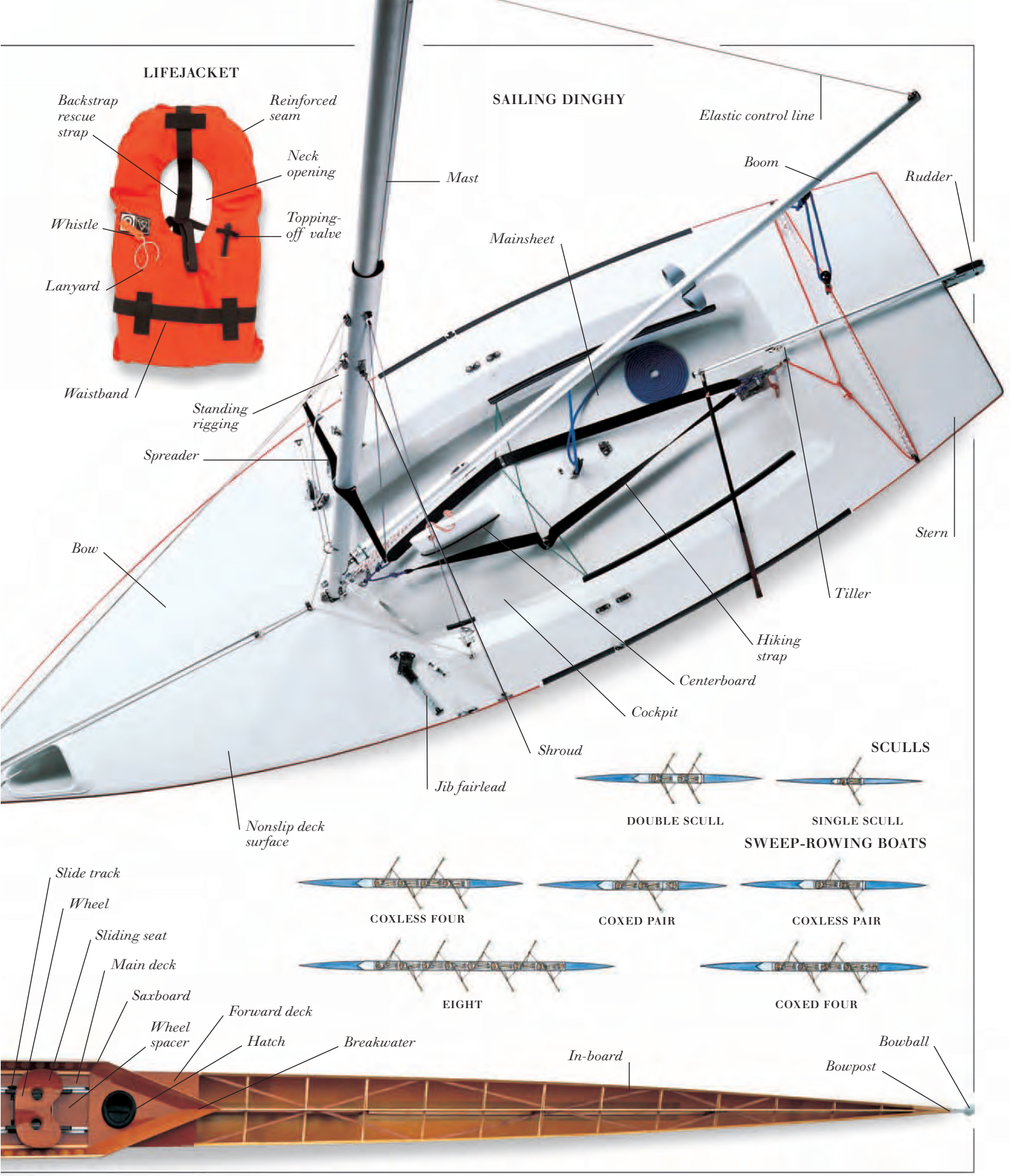
KICKING DOWN

WHOLE BODY UNDULATION

Canoeing, rowing, and sailing

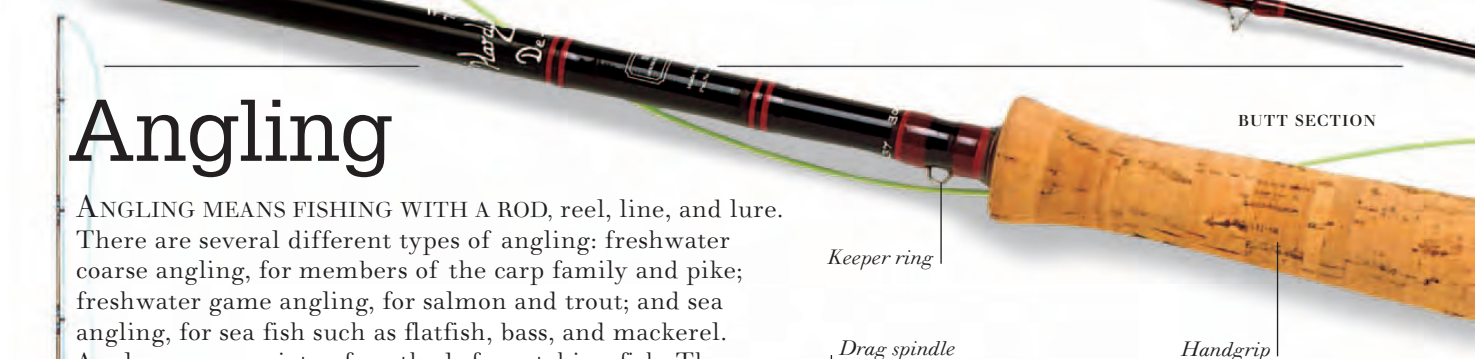
WATERBORNE SPORTS are as varied as the crafts used. There are two disciplines in rowing; sweep rowing, in which each rower has one oar, and sculling, in which rowers use two oars. There are a number of different Olympic and competitive rowing events for both men and women. The number of rowers and weight classes vary. Some rowing events use a coxswain; a steersman who does not row but directs the crew. Kayaks and canoes are used in straight sprint and slalom races. Slalom races take place over a course consisting of 20 to 25 gates, including at least six upstream gates. In yacht racing, competitors must complete prescribed courses, organized by the race committees, in the shortest possible time, using sail power only. Olympic events include classes for keel boats, dinghies, and catamarans.



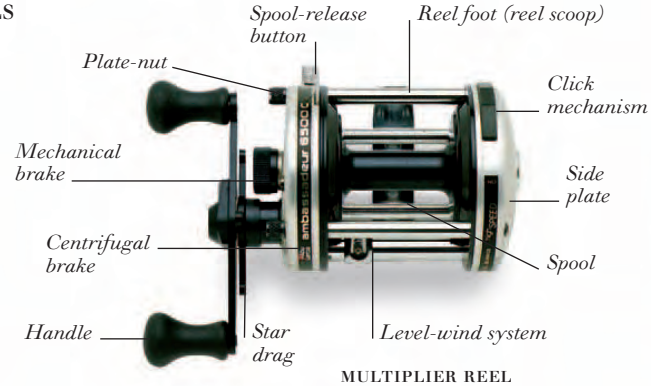

LIFEJACKET
Backstrap rescue strap
Reinforced seam
Neck opening
Whistle
Topping-off valve
Lanyard
Waistband
SAILING DINGHY
Elastic control line
Mast
Boom
Rudder
Mainsheet
Standing rigging
Spreader
Bow
Stern
Tiller
Hiking strap
Centerboard
Cockpit
Shroud
Jib fairlead
Nonslip deck surface
SCULLS
DOUBLE SCULL
SINGLE SCULL
SWEEP-ROWING BOATS
COXLESS FOUR
COXED PAIR
COXLESS PAIR
EIGHT
COXED FOUR
Slide track
Wheel
Sliding seat
Main deck
Saxboard
Wheel spacer
Forward deck
Hatch
Breakwater
In-board
Bowball
Bowpost

Angling

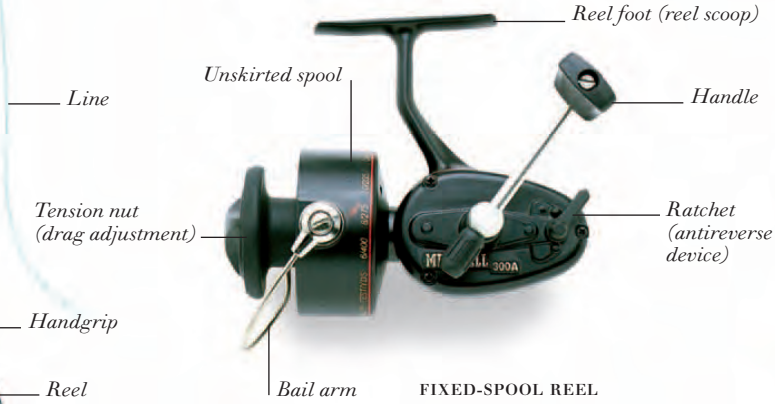
ANGLING MEANS FISHING WITH A ROD, reel, line, and lure. There are several different types of angling: freshwater coarse angling, for members of the carp family and pike; freshwater game angling, for salmon and trout; and sea angling, for sea fish such as flatfish, bass, and mackerel. Anglers use a variety of methods for catching fish. These include bait fishing, in which bait (food to allure the fish) is placed on a hook and cast into the water; fly fishing, in which a natural or artificial fly is used to lure the fish; and spinning, in which a lure that looks like a small fish revolves as it is pulled through the water. The angler uses the rod, reel, and line to cast the lure over the water. The reel controls the line as it spills off the spool and as it is wound back. Weights may be fixed to the line so that it will sink. Swivels are attached to prevent the line from twisting. When a fish bites, the hook must become embedded in its mouth and remain there while the catch is reeled in.



REELS

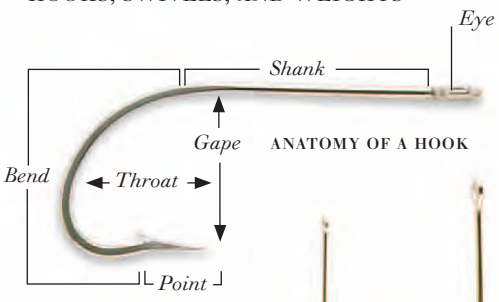


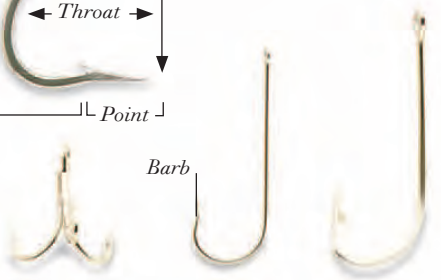
MULTIPLIER REEL



FIXED-SPOOL REEL

HOOKS, SWIVELS, AND WEIGHTS

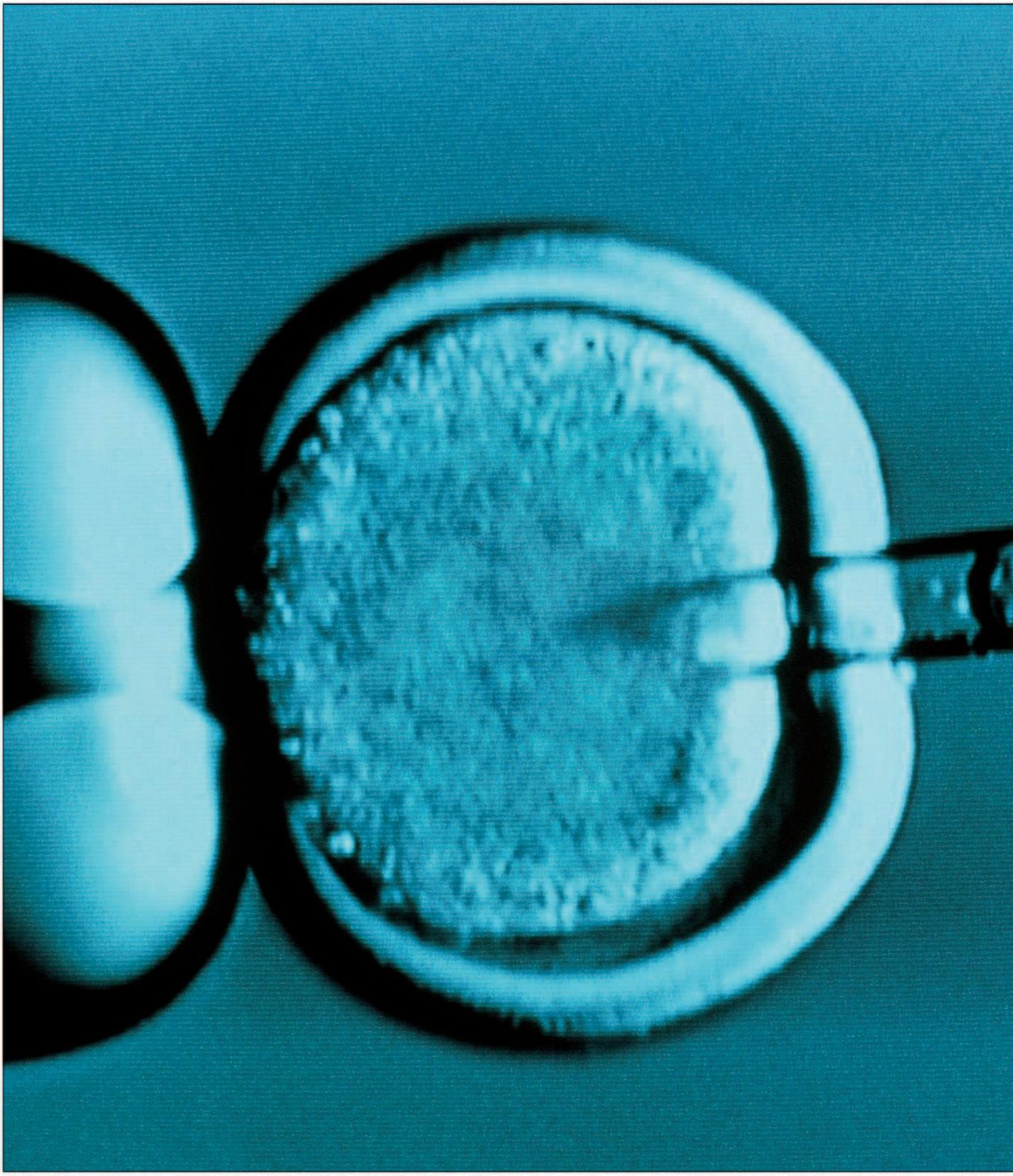


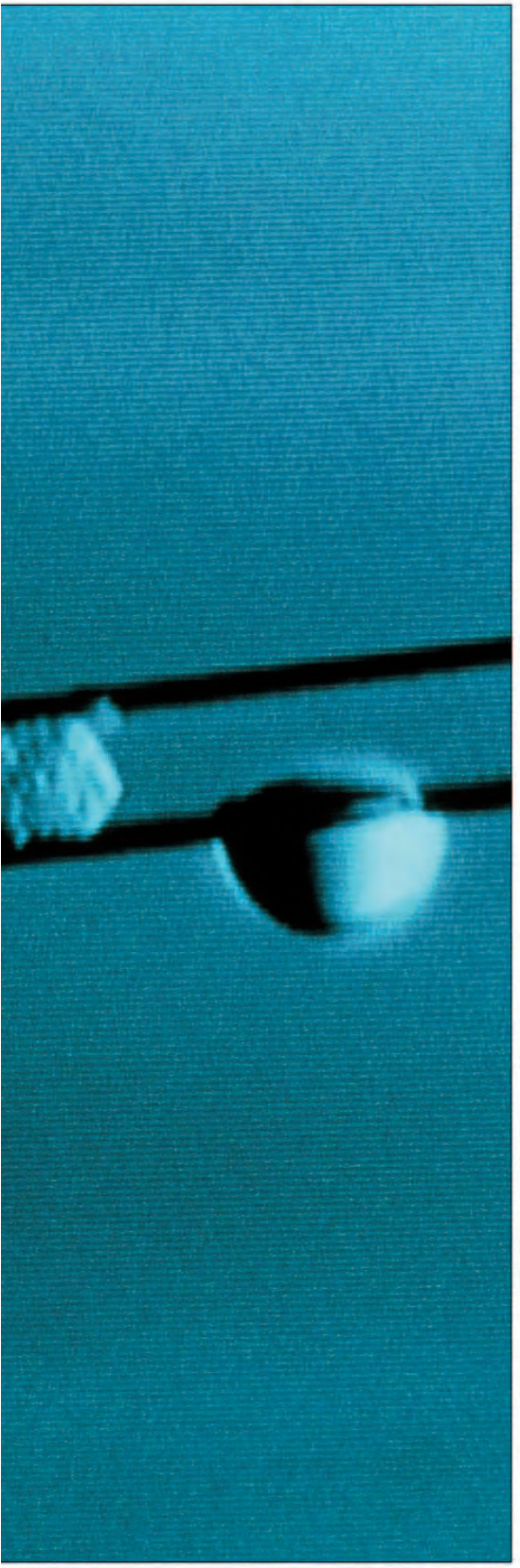


TREBLE HOOK | ABERDEEN HOOK | REVERSED BEND HOOK

EXAMPLES OF BARREL SWIVELS | HILLMAN ANTIKINK WEIGHT

FLY ROD AND REEL
Intermediate ring
TIP SECTION
Reel seat
Screw locking nut
Tip ring
Disk drag housing
Reel foot (reel scoop)
Line
Butt cap
Drag knob screw
Butt extension
Clicker plate
Drag knob
DragonFly 100
Disc Drag
Release lever
Spool screw
Release spring
Spool cover
Spool-release button
Handle
ARTIFICIAL FLIES
Line guide
DUNKELD WET FLY
Tail
Body
Cheek
Head
Line guide cover
Hackle
Retaining screw
Ribbing
ARTIFICIAL LURES
DEVON MINNOW
Fin
Eye
Treble hook
Swivel
Tulip mount
DEER HOPPER DRY FLY
Front hackle
Eye
Tail
Hook
Wing
Head
JOINTED PLUG
Adjustable vane
Joint
Treble hook





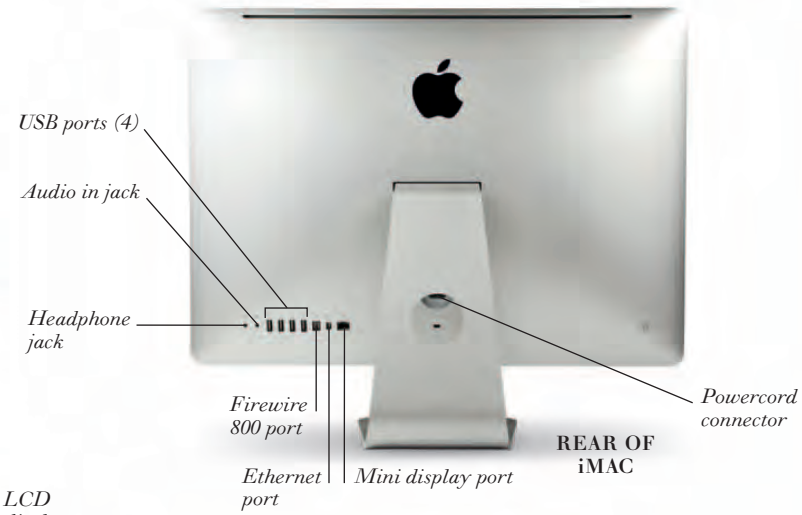
The Modern World

Personal Computer 566
Handheld Computer 568
Flatbed Scanner 570
Airbus 380 572
Inkjet Printer 574
The Internet 576
Electronic Games 578
Digital Camera 580
Digital Video Camera 582
Home Cinema 584
Personal Music and Video 586
Cellphones 588
Global Positioning System 590
Vacuum Cleaner 592
Iron and Washer-dryer 594
Microwave Combination Oven 596
Toaster 598
Drill 600
House of the Future 602
Renewable Energy 604
Cloning Technology 606
Robots 608
High-performance Microscopes 610
Space Telescope 612
Probing the Solar System 614

Personal computer

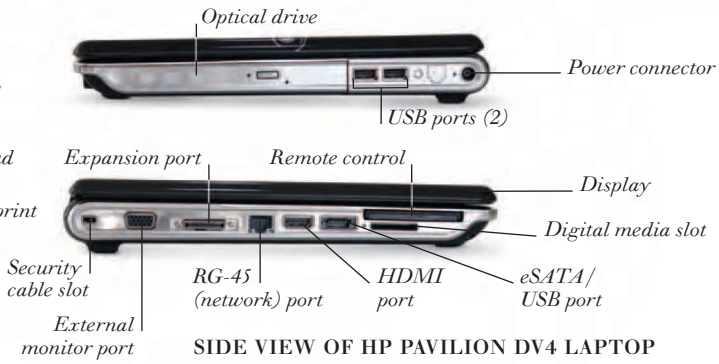
PERSONAL COMPUTERS (PCs) fall into two main types: IBM-compatible PCs, known simply as PCs, and Apple Macintosh PCs, known as "Macs." They differ in the way files and programs, and the user's access to them, are organized, and programs must be tailored for each type. However, in most other respects PCs and Macs have much in common. Both contain microchips, or integrated circuits, that store and process data. The "brain" of any PC is a chip known as the central processing unit (CPU), which performs mathematical operations in order to run program instructions and receive, store, and output data. The most powerful personal computer CPUs today can perform more than a billion calculations a second. Data can be input via CDs, USB memory sticks, and other storage media. Highly portable laptop and network PCs are also in widespread use. Most PCs are able to communicate with many other devices, including digital cameras (see pp. 580-81) and smartphones (see pp. 588-89).

iMAC



REAR OF iMAC

HP PAVILION DV4 LAPTOP



SIDE VIEW OF HP PAVILION DV4 LAPTOP

SYSTEM UNIT OF A PC

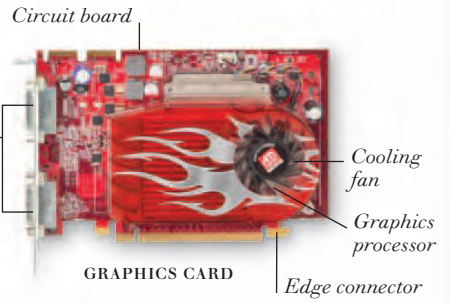
COMPONENTS OF A SYSTEM UNIT

COOLING FAN

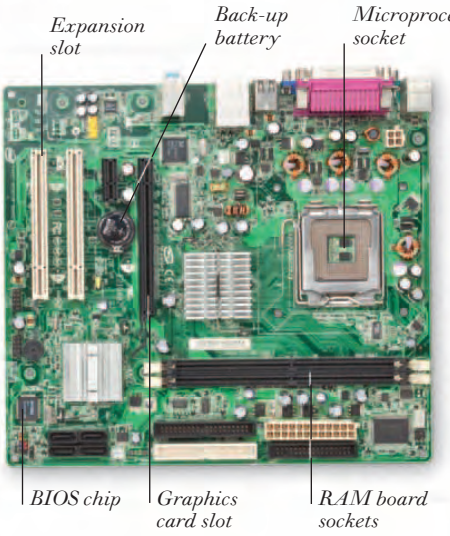
RAM BOARD

CD DRIVE

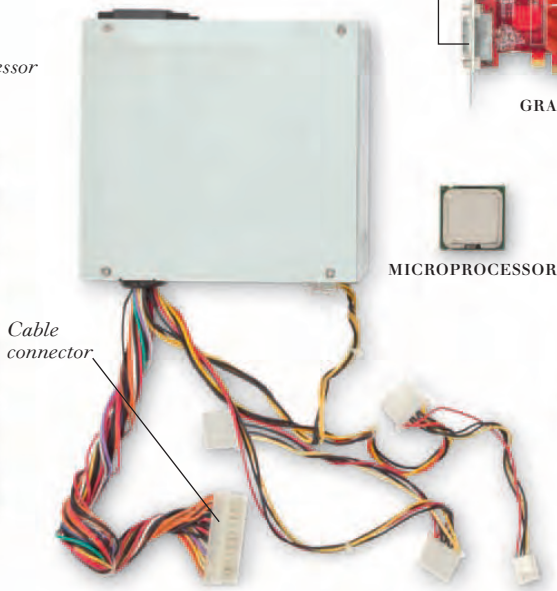
SIDE CABLE



GRAPHICS CARD



MOTHERBOARD



POWER SUPPLY

MICROPROCESSOR

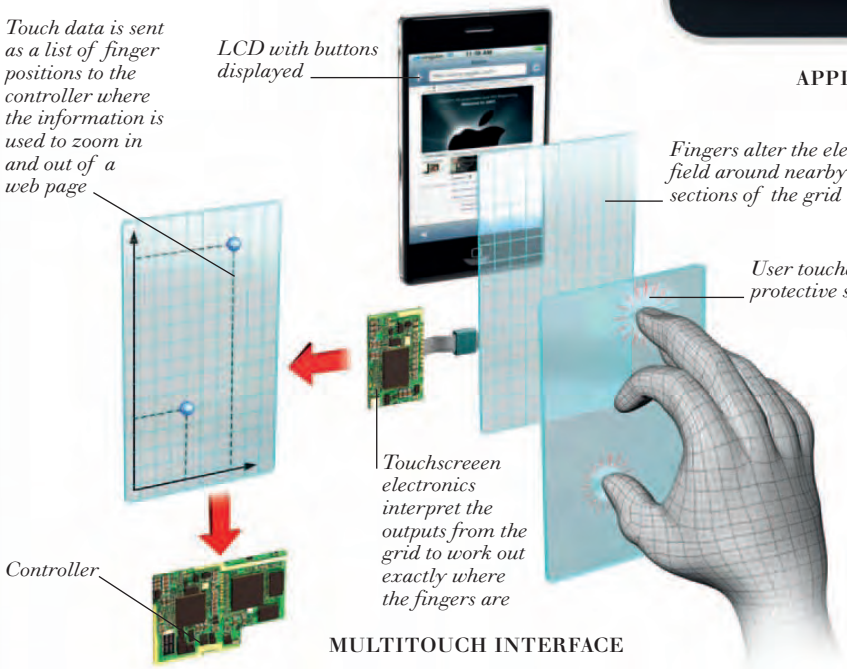
HARD DISC DRIVE

DATA CABLE

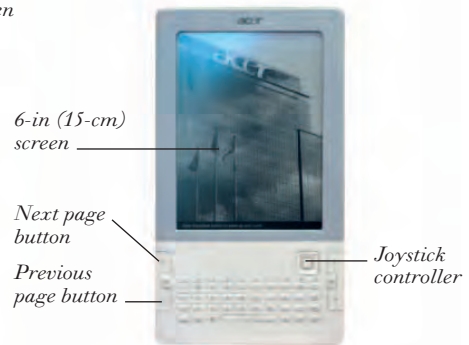
Handheld computer

By the early 1990s electronic circuitry had been miniaturized to such an extent that it was possible to make small handheld computing devices. The first of these was the Personal Digital Assistant (PDA), which offered features including an address book, calendar, and notepad. In recent years, PDAs have been overtaken by smartphones with internet and email access (see pp. 588–589). A related product is the e-book reader, which stores books in digital form and uses "electronic paper" to mimic the appearance of ink on real paper. An e-book reader no bigger than a thin paperback can store several thousand digital books in its memory. The most recent small computing device is the handheld computer. This looks like a thin flat display, but it is actually a complete computer. Handheld computers are typically controlled by a touch-sensitive screen and have a wireless link to other computers and the internet. They run software applications, or apps, downloaded from the internet. The most popular handheld computer currently is the Apple iPad. It has a multitouch interface that enables its screen to detect the movements of fingertips. In addition to selecting options and apps by touching the screen, images can be enlarged or shrunk by moving fingertips apart or together on the screen.

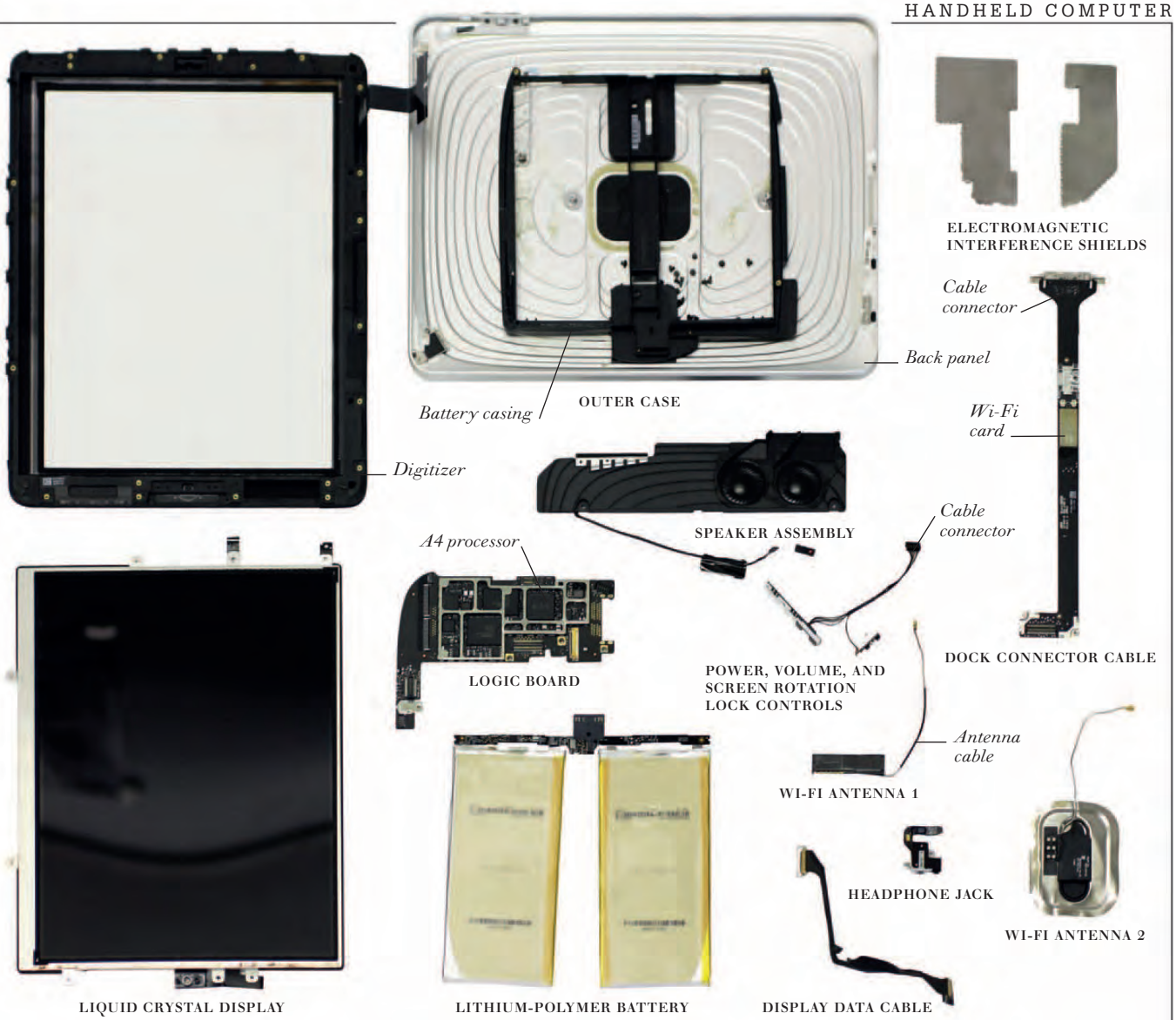
APPLE IPAD



MULTITOUCH INTERFACE



ACER LUMIREAD E-READER



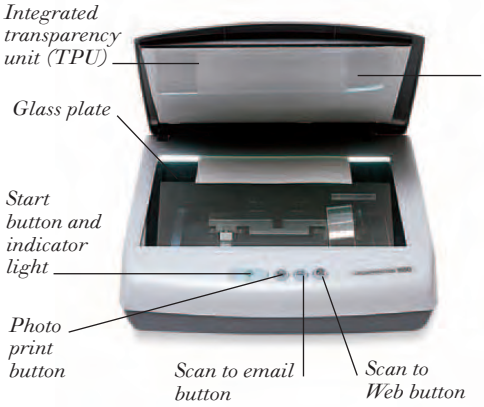
COMPONENTS OF AN APPLE IPAD

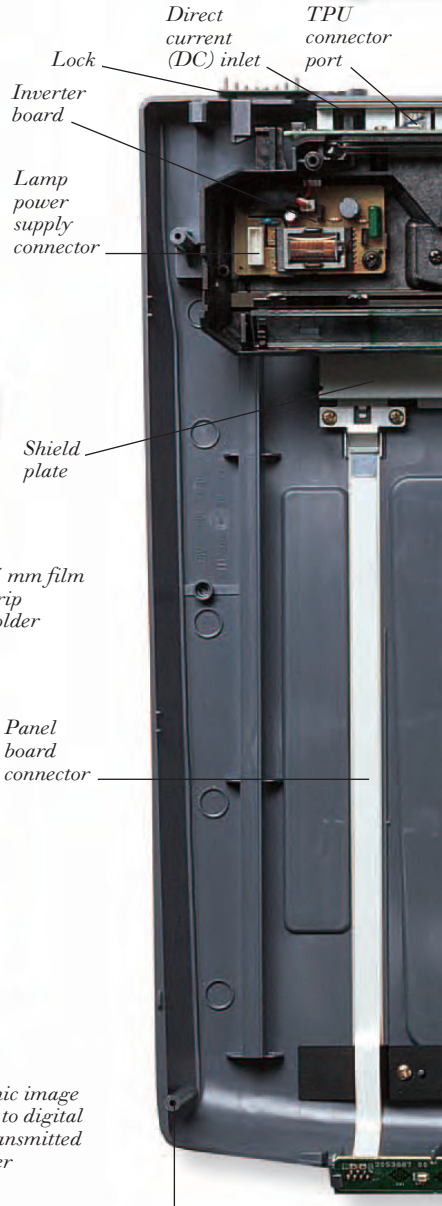
OTHER TABLET COMPUTERS

Flatbed scanner

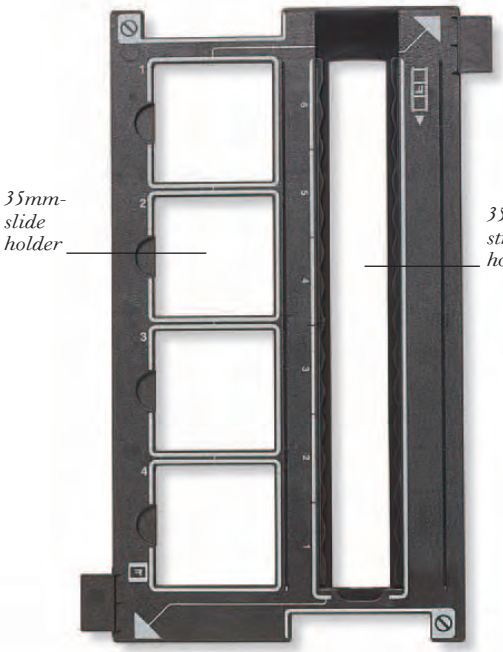
SCANNERS CONVERT physical images into electronic form, allowing them to be sent over the internet, displayed on a website, stored on a computer, and manipulated using specialized software. Scanners work by detecting and analyzing light reflected from an opaque image, such as a photographic print. Some can also scan photographic transparencies by analyzing light that has passed through the image. Flatbed scanners contain a unit, called the scan head, that contains a lamp, mirrors, a lens, and an array of CCDs (Charge-Coupled Devices). The carriage passes beneath the image; the lamp shines light on to or through the original; the mirrors reflect the light on to the lens, which focuses it on to the CCD array. Each CCD detects the brightness of light from a particular pixel (picture element) along a· horizontal strip and converts this data into an electric signal. For color images, the light is usually passed through red, green, and blue filters and then directed to the CCD array so that it can be broken down into its component colors. This information is then converted to digital form. The quality of the image depends on its resolution, measured in dpi (Dots Per Inch).

SCANNER

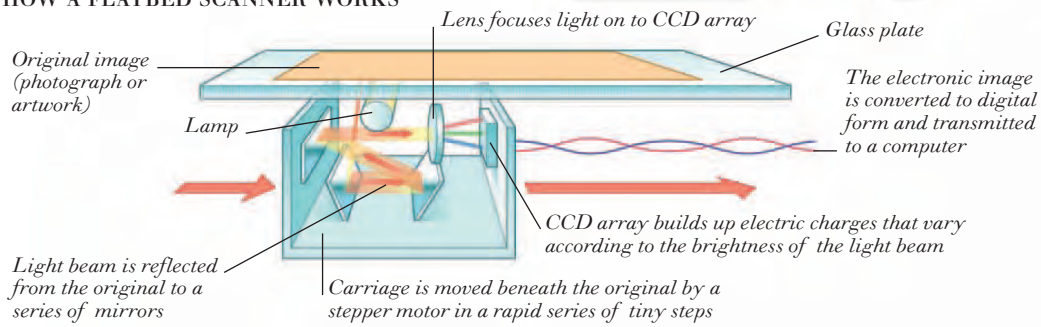


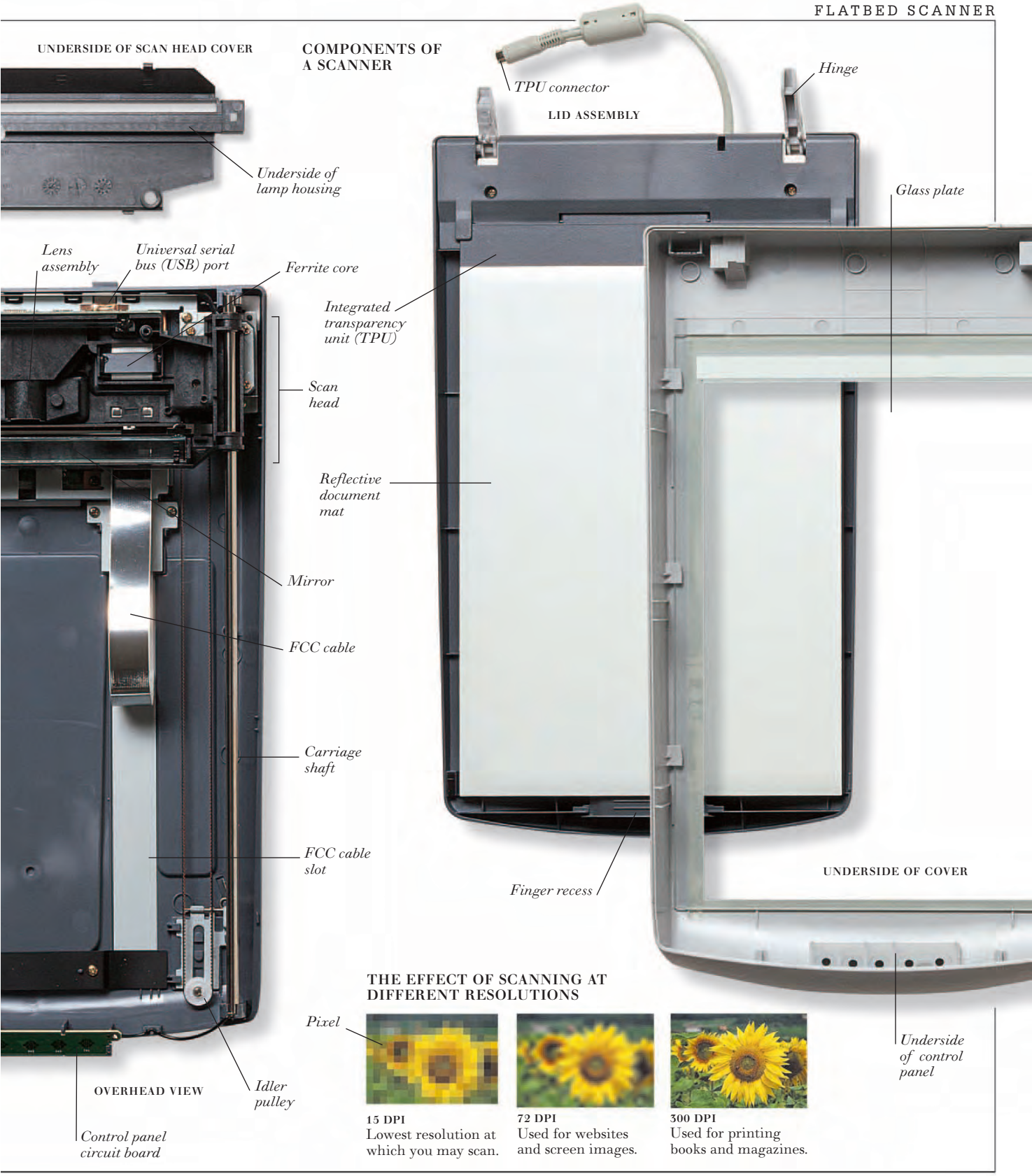


FILM AND SLIDE HOLDER



HOW A FLATBED SCANNER WORKS





THE EFFECT OF SCANNING AT DIFFERENT RESOLUTIONS

15 DPI
Lowest resolution at which you may scan.

72 DPI
Used for websites and screen images.

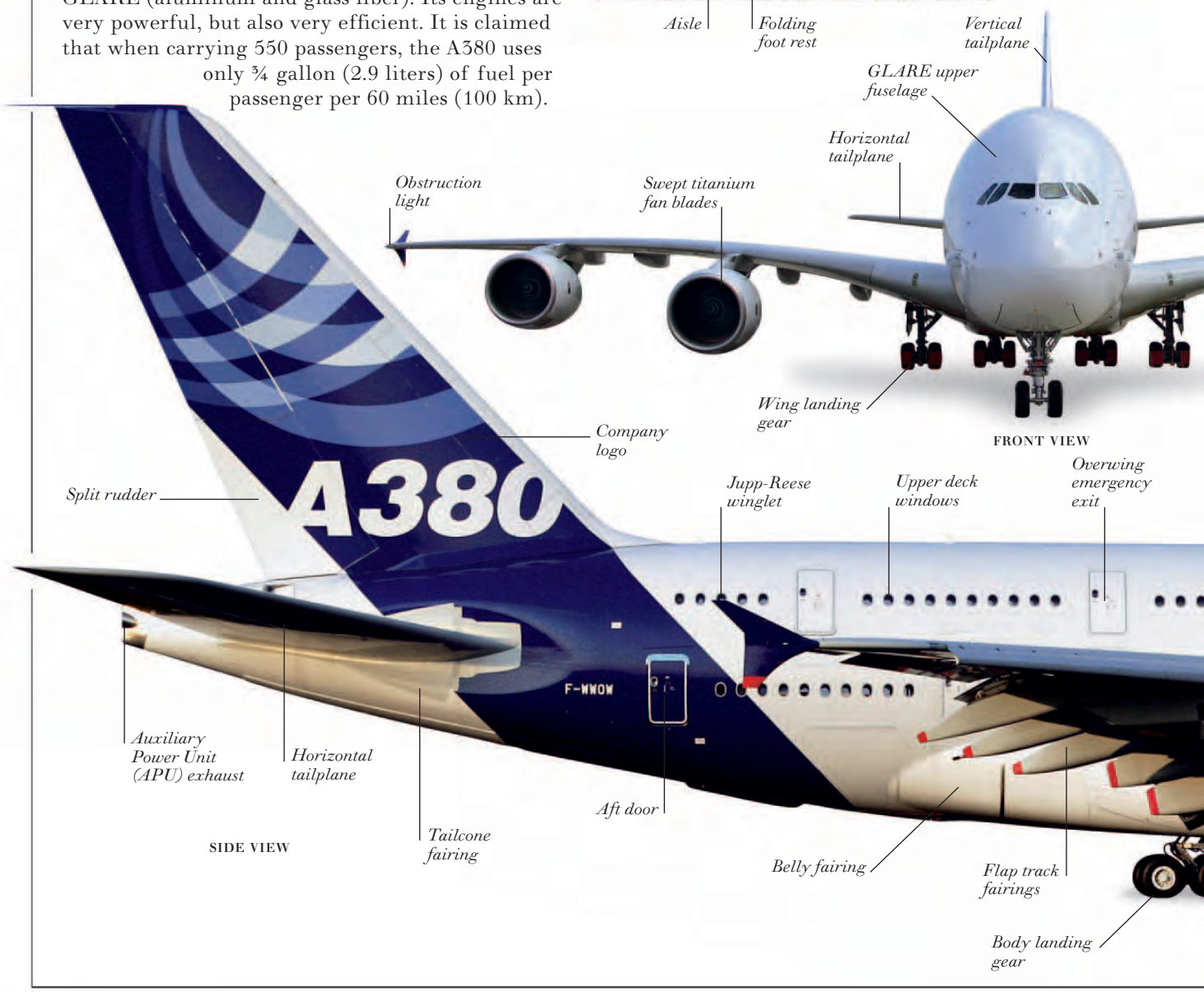
300 DPI
Used for printing books and magazines.

Airbus 380

CROSS-SECTION OF FUSELAGE

THE AIRBUS A380 WAS CONCEIVED in the early 1990s to compete with, and if possible replace, the Boeing 747. Work began in earnest on what was then called the A3XX in 1994. Its maiden flight was in April 2005. The A380's shape is subtly molded to minimize drag from its ovoid fuselage. The structure makes extensive use of composite materials, such as thermoplastics and GLARE (aluminum and glass fiber). Its engines are very powerful, but also very efficient. It is claimed that when carrying 550 passengers, the A380 uses only ¾ gallon (2.9 liters) of fuel per passenger per 60 miles (100 km).

INTERIOR VIEW OF BUSINESS CLASS CABIN

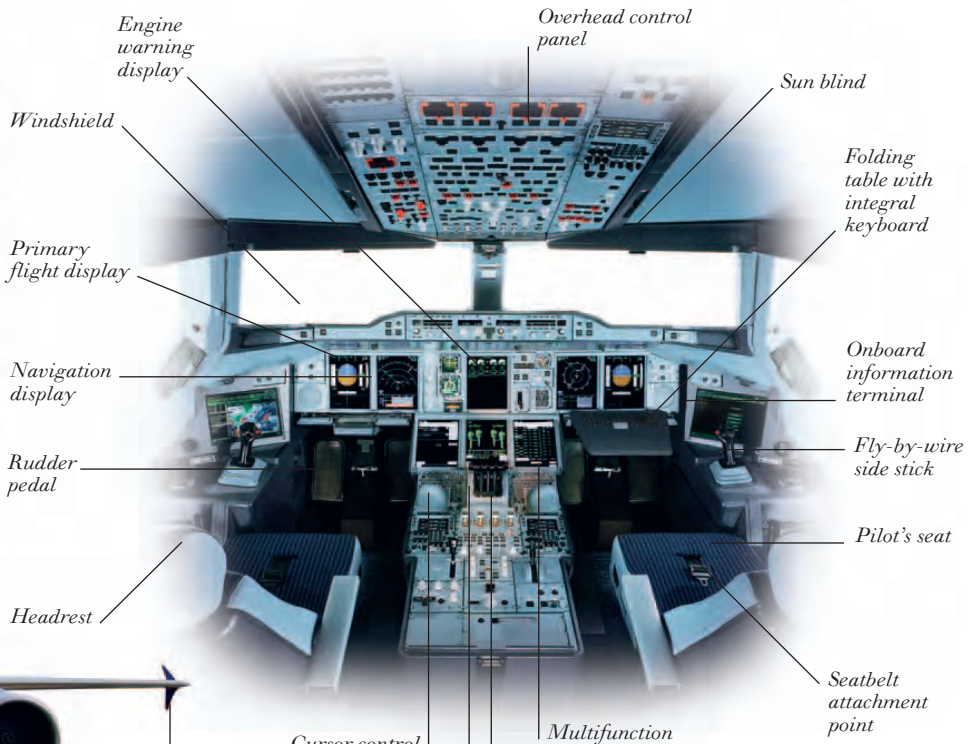


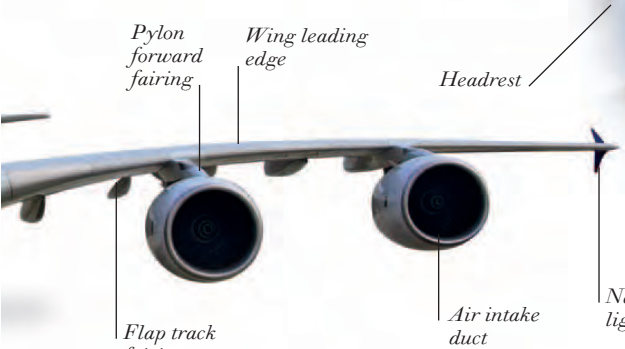
FRONT VIEW

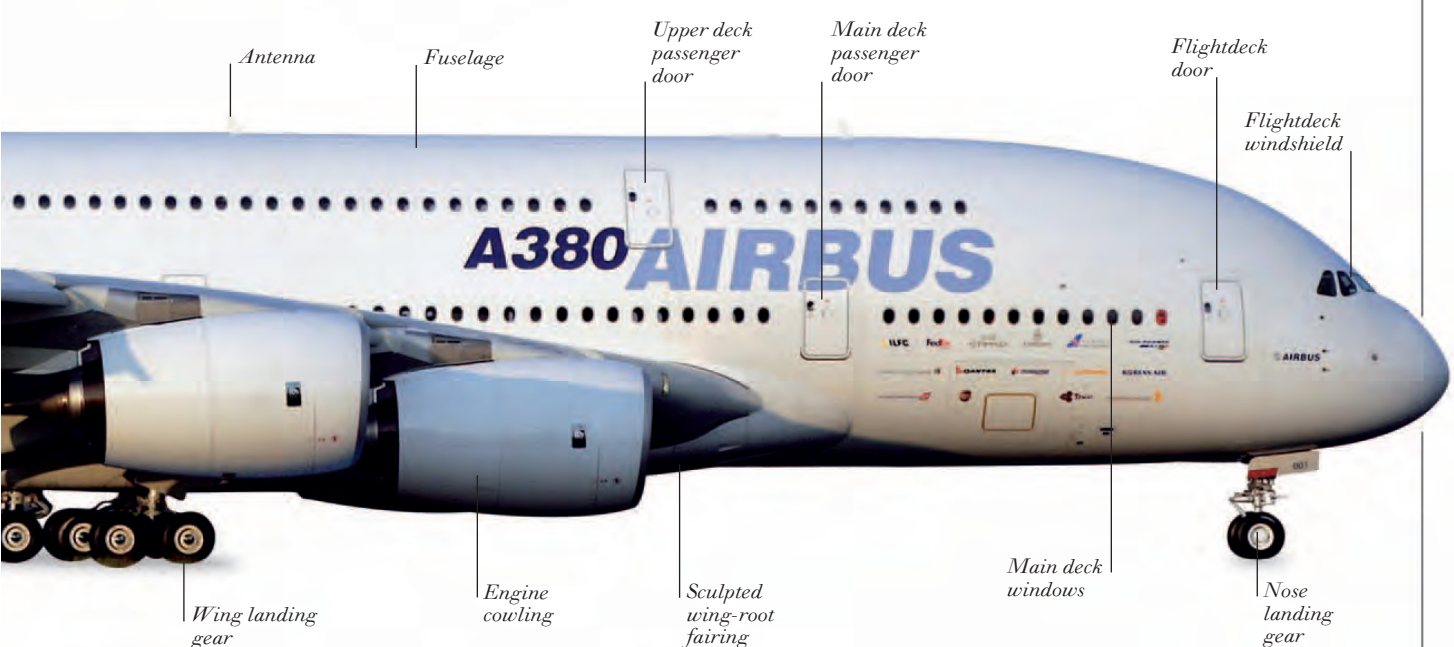
SIDE VIEW

INTERIOR VIEW OF GALLEY

COCKPIT



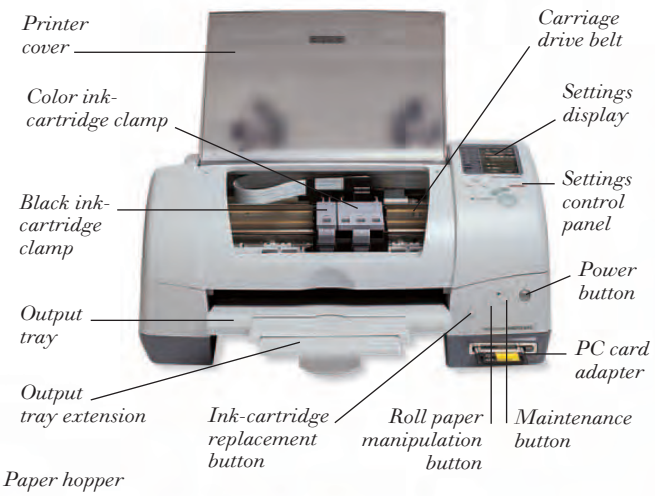




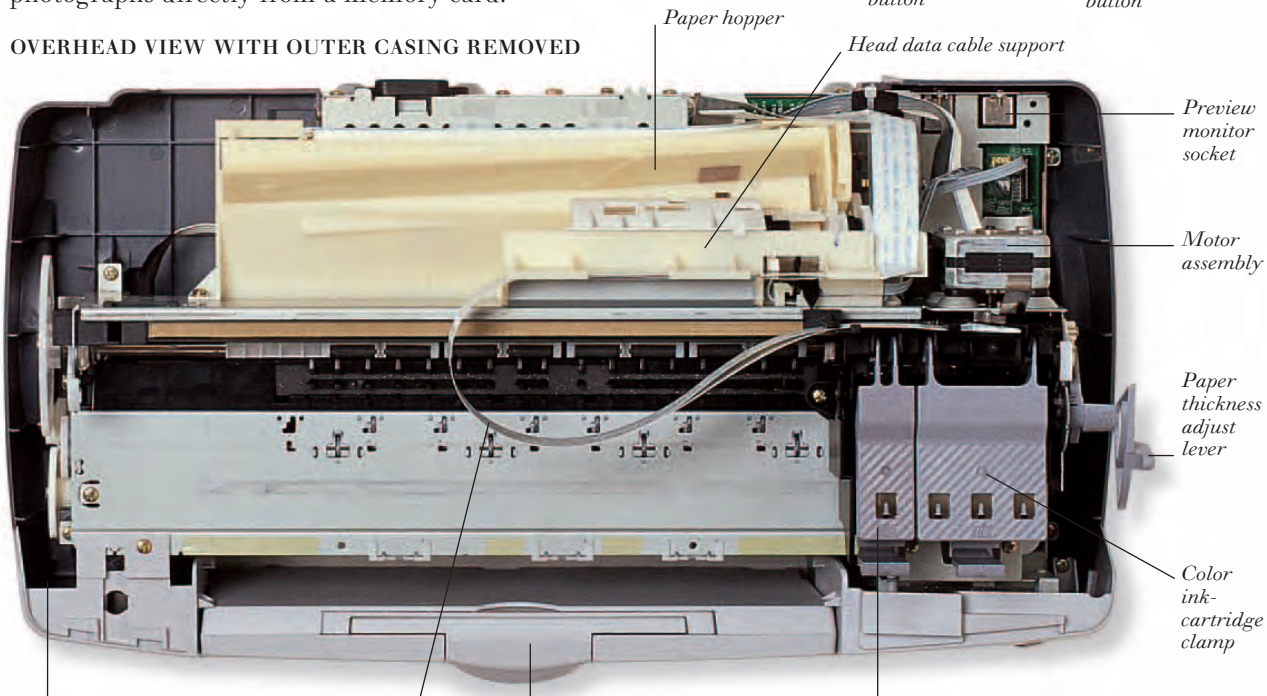
Inkjet printer

INKJET PRINTERS EXPEL ink droplets from hundreds of tiny jets, or nozzles, on to a medium, such as paper, to print an image. Each droplet corresponds to a single pixel (picture element). Black-and-white printers use only black ink, while color printers overprint combinations of the printing colors (cyan, yellow, magenta, and black) to create a full color range. The printhead containing the nozzles moves sideways across the paper, creating a line of pixels, before the paper moves slightly forward so the next line can be printed. Two basic methods are used to eject ink: thermal, in which ink is heated to form an expanding bubble that expels a droplet from the nozzle, and piezoelectric, in which an electric current expands a crystal causing it to push out the ink droplet. The printer shown here can print digital photographs directly from a memory card.

EPSON STYLUS PHOTO 895 COLOR INKJET PRINTER



OVERHEAD VIEW WITH OUTER CASING REMOVED

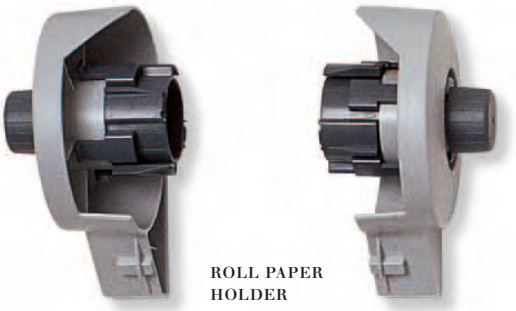


INK CARTRIDGES

PC CARD ADAPTER

PAPER FEED COMPONENTS

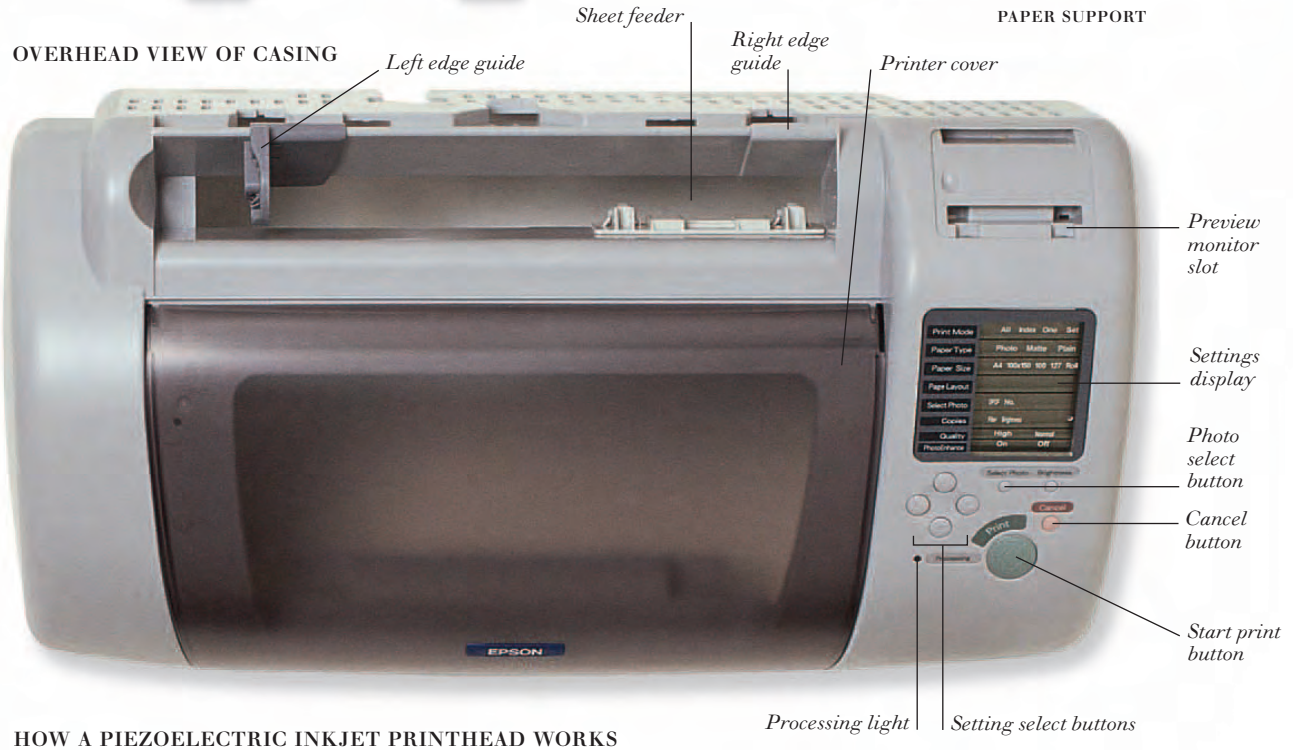
ROLL PAPER HOLDER ADAPTER



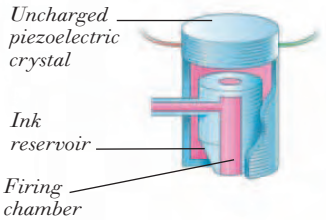
ROLL PAPER HOLDER

PAPER SUPPORT

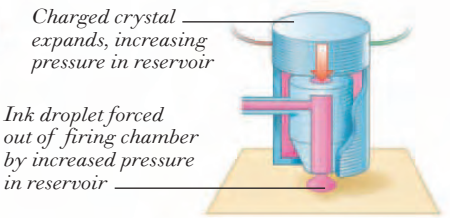
OVERHEAD VIEW OF CASING



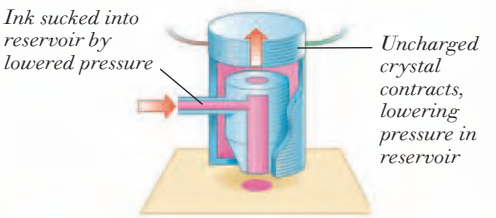
HOW A PIEZOELECTRIC INKJET PRINTHEAD WORKS



INKJET NOZZLE



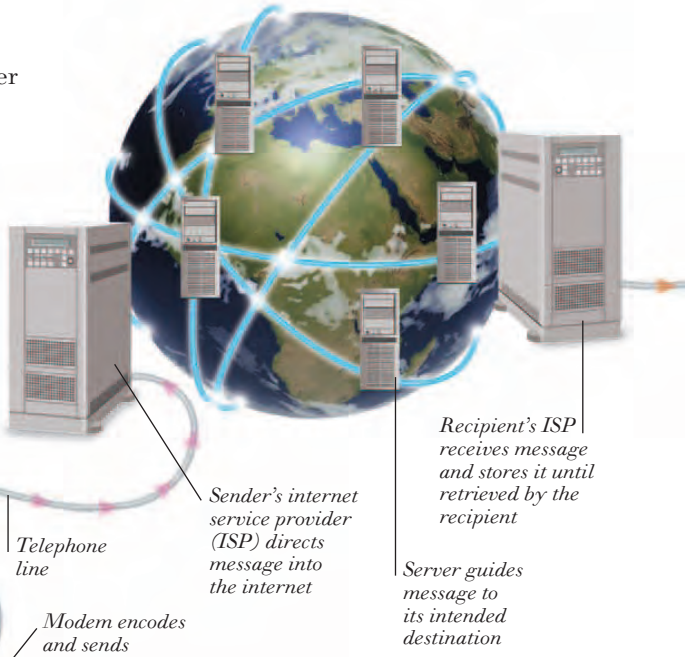
DROPLET EJECTED



CHAMBER REFILLED

The internet

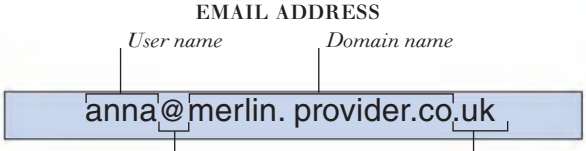
THE INTERNET CONSISTS OF TENS of thousands of computer networks linked together to form one huge global network, allowing any computer on one network to communicate with any computer on another. The two main services used on the internet are email and the World Wide Web. Email allows text messages to be sent—along with attached computer files, images, or video clips, for example—to other computers on the internet. The web consists of billions of pages made up of digital files that are stored on computers across the world and can be viewed using a web browser. The web also provides interactive access to various services, for example, banking and shopping.



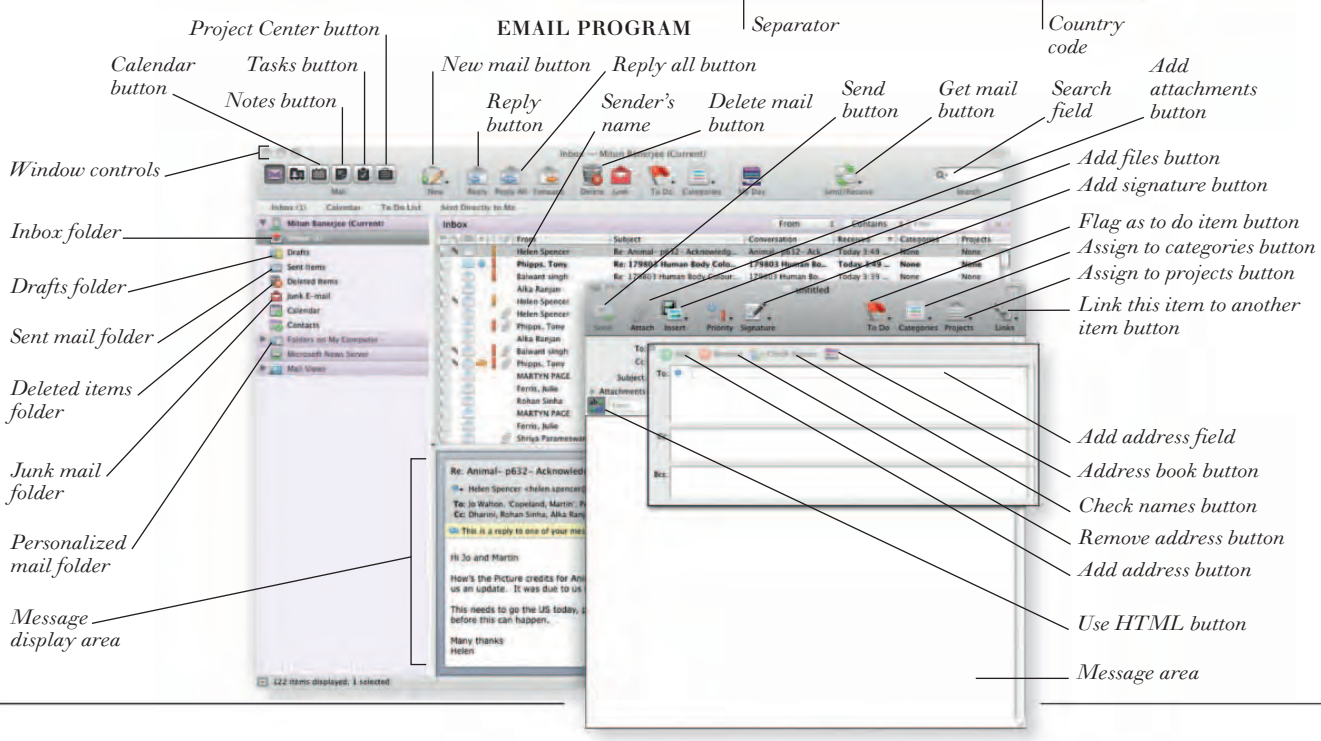
HOW EMAIL WORKS

EMAIL SENDER

EMAIL ADDRESS

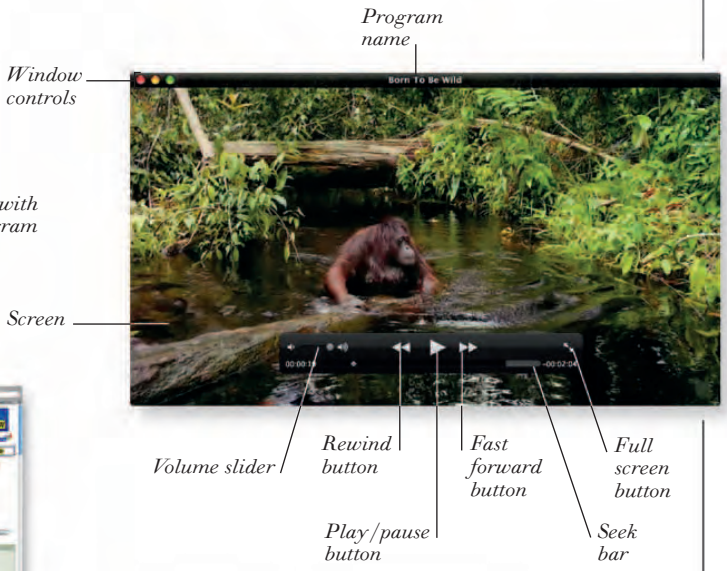


EMAIL PROGRAM

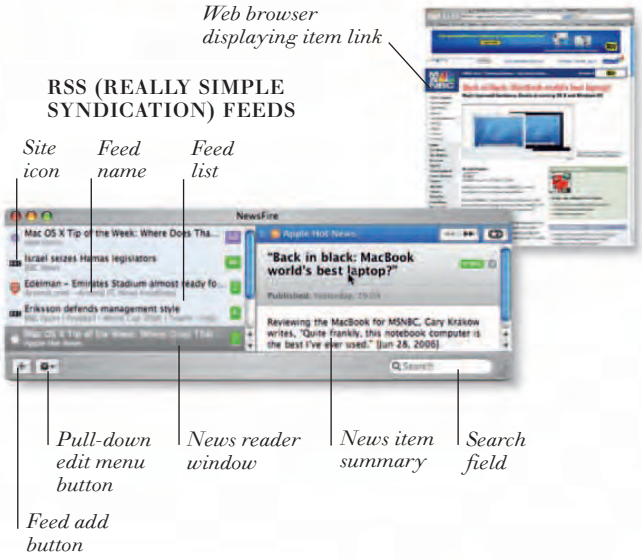


EMAIL RECIPIENT

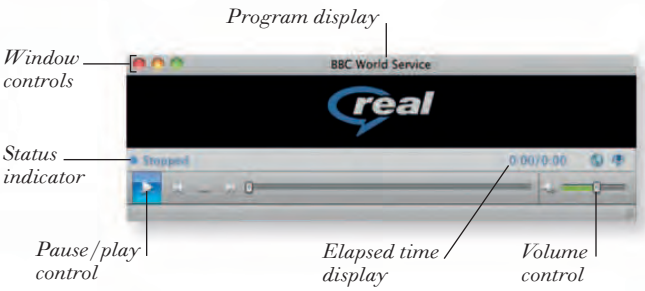
STREAMED INTERNET VIDEO ON-SCREEN DISPLAY



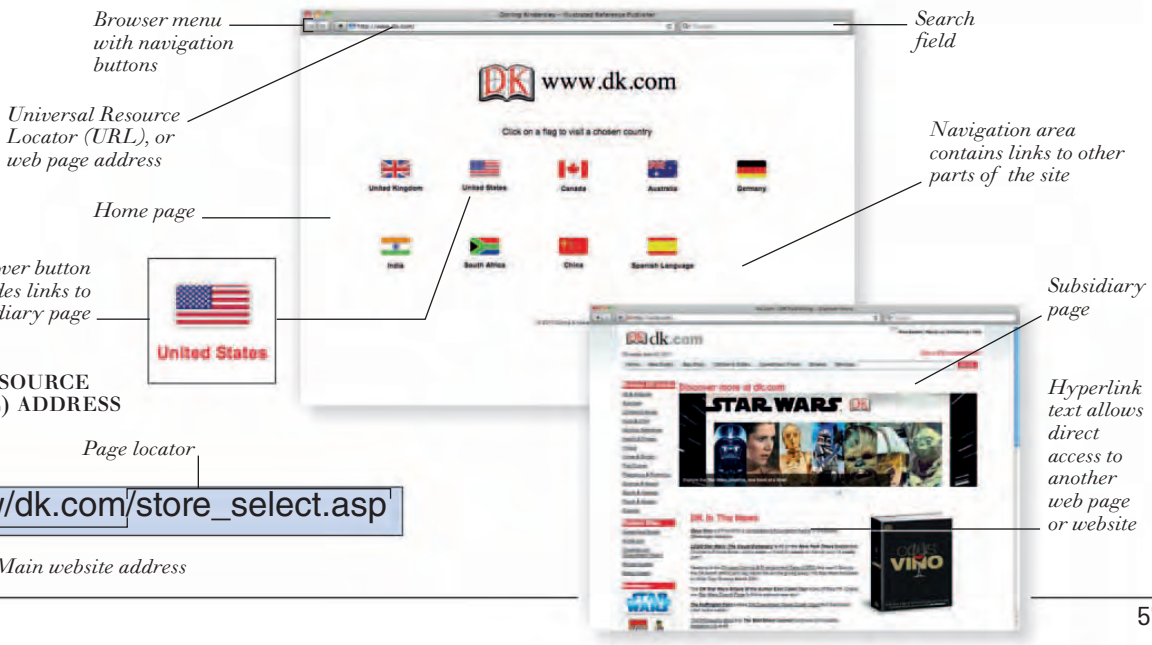
RSS (REALLY SIMPLE SYNDICATION) FEEDS



STREAMED INTERNET RADIO ON-SCREEN DISPLAY



WEB PAGES



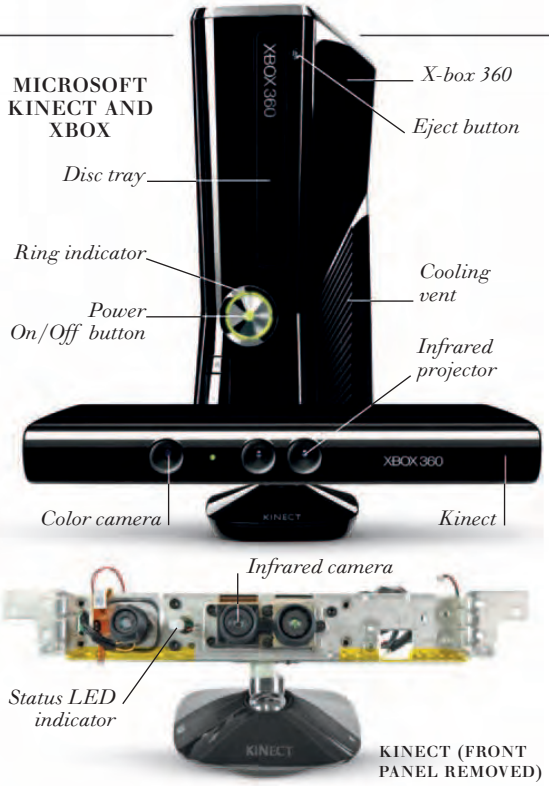
UNIVERSAL RESOURCE LOCATOR (URL) ADDRESS

Electronic games

MARIO SPORTS MIX WII

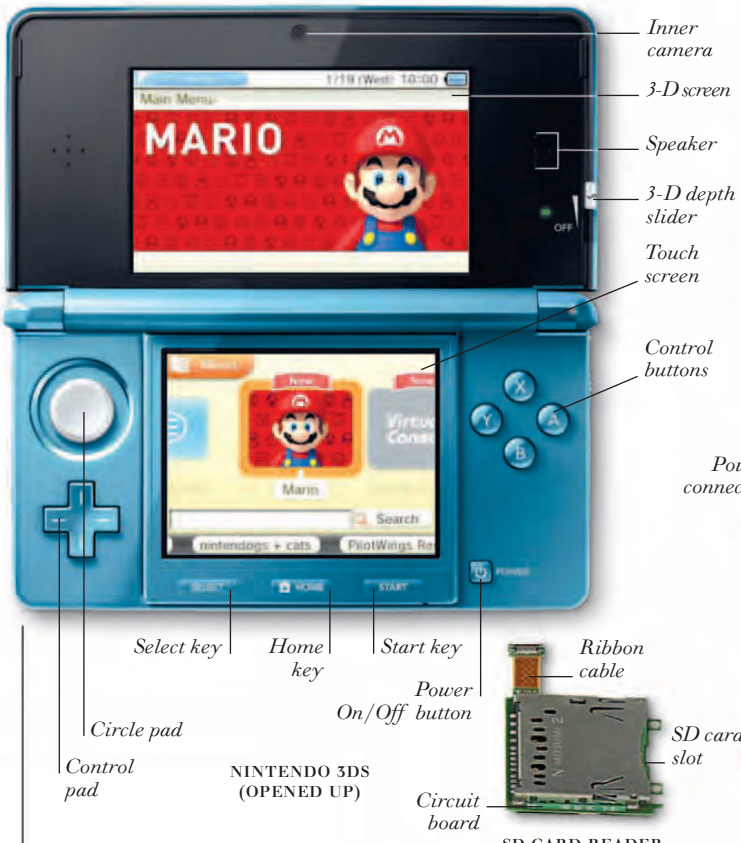
VIDEO GAMES HAVE BEEN around since the early 1970s. They are played on PCs, arcade machines, on a TV using a home console, and on portable handheld consoles. Players use devices such as joysticks and control pads with buttons to control movement and action on screen. The latest generation of consoles uses motion sensor technology to allow players to manipulate objects on screen by simply moving the controller. The most advanced game systems respond to gestures and commands spoken by a player, without any need to use a hand controller. The game itself is stored in the form of digital information on CD, DVD, or microchip—which may be integral or stored in a removable cartridge—or on an internal hard disk. A central processing unit (CPU) (see pp. 566–567) is needed to process commands from the players, while specialized graphics chips are used to process the complex mapping and texturing functions that make modern games appear so realistic.

MICROSOFT KINECT AND XBOX



KINECT (FRONT PANEL REMOVED)

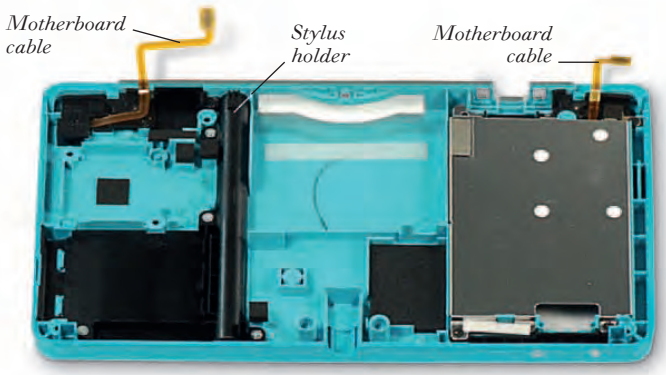
NINTENDO 3DS



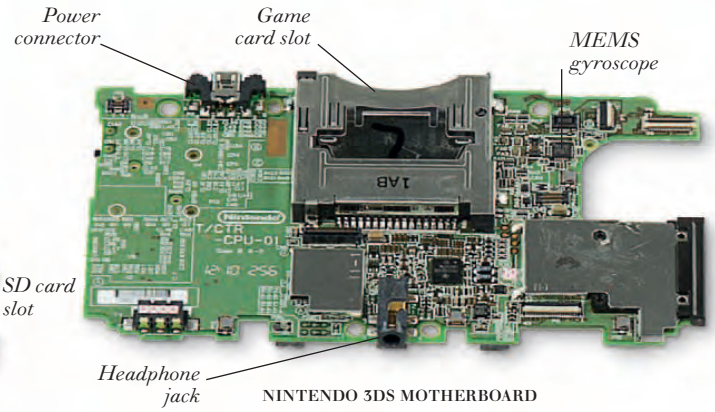
NINTENDO 3DS (OPENED UP)

SD CARD READER

COMPONENTS OF NINTENDO 3DS



LOWER CASE BASE

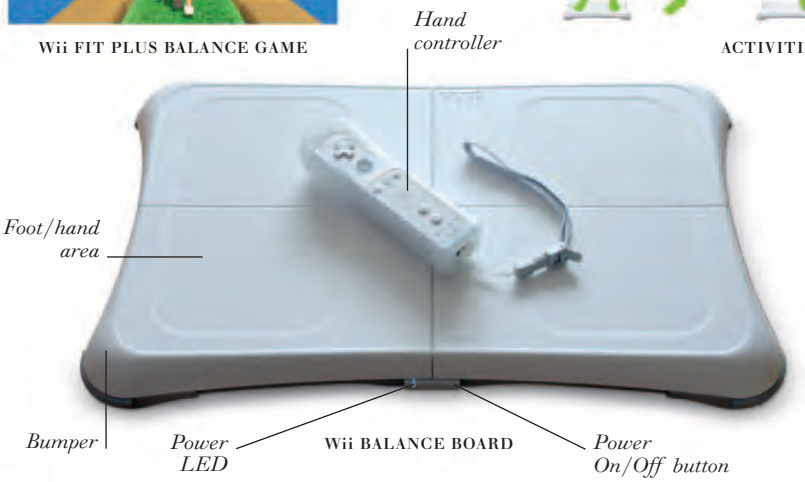


NINTENDO 3DS MOTHERBOARD

NINTENDO Wii FIT PLUS

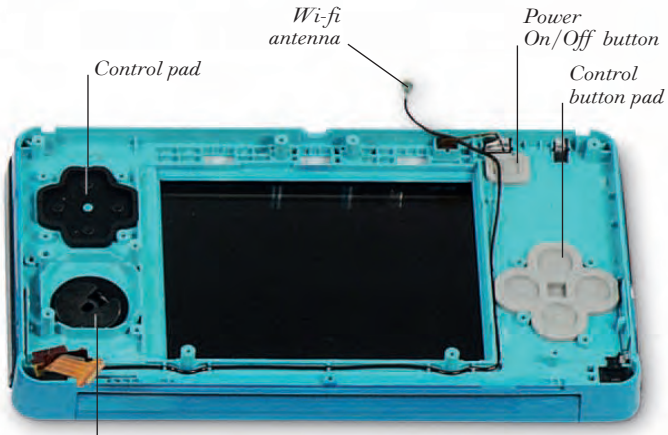
Wii FIT PLUS BALANCE GAME

ACTIVITIES ON A BALANCE BOARD

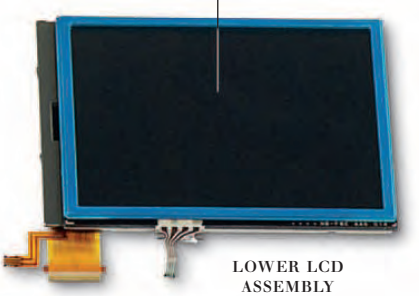


Wii BALANCE BOARD

Wii HAND CONTROLLER



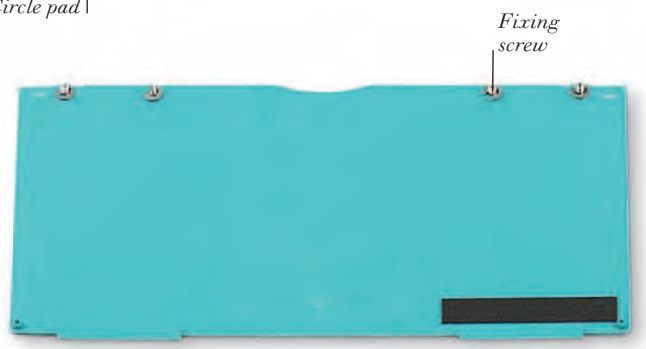
LOWER CASE TOP



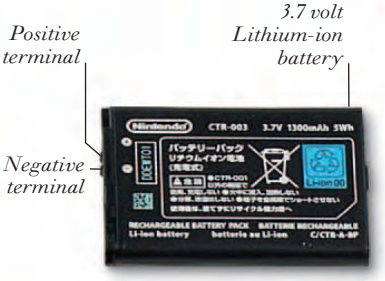
LOWER LCD ASSEMBLY

WI-FI BOARD

INFRARED BOARD



BATTERY COVER



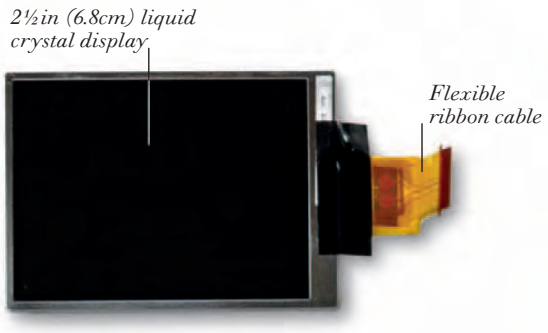
RECHARGEABLE BATTERY

VOLUME CONTROL

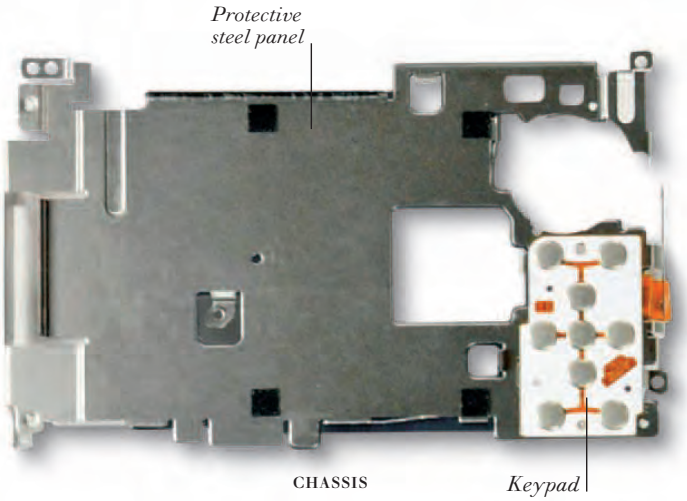
CIRCLE PAD

Digital camera

FOR MORE THAN 200 YEARS, CAMERAS recorded pictures as chemical changes in silver-containing substances, on a strip of flexible, celluloid film. The digital camera records pictures in electronic form. At its heart is a specialized integrated circuit known as a charge-coupled device (CCD). This has millions of microunits known as pixels. It works in the opposite way from a miniature computer or TV screen. Instead of electric signals making pixels shine, when light hits a pixel it generates a tiny electrical signal, according to the light's color and brightness. The signals from the CCD's millions of pixels are analogue: they vary continuously in a wavelike fashion. They are converted by a microchip to digital codes of numbers, represented as on-off electronic pulses. The digital signals are processed and fed to the camera's internal memory or a removable memory device such as a data card or memory stick. Photographs can be downloaded from a digital camera to a computer via a cable or in some cases a wireless link. Some digital cameras automatically reduce blurring caused by camera shake or fast movement, some can record video clips as well as still pictures.

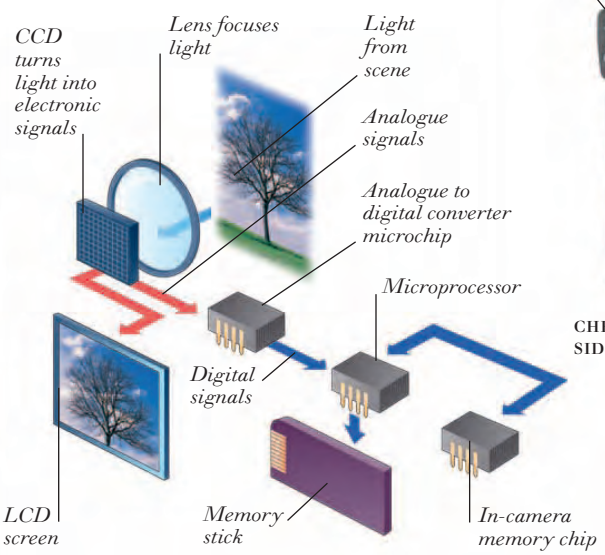


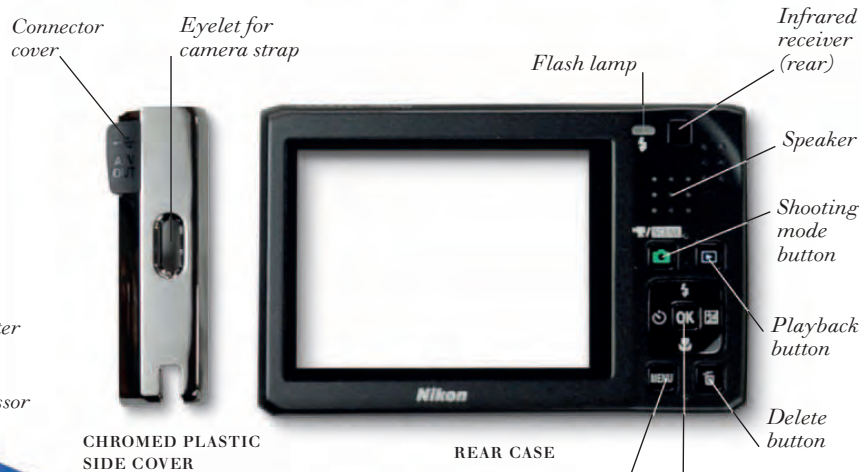
MONITOR



CHASSIS

HOW A DIGITAL CAMERA WORKS





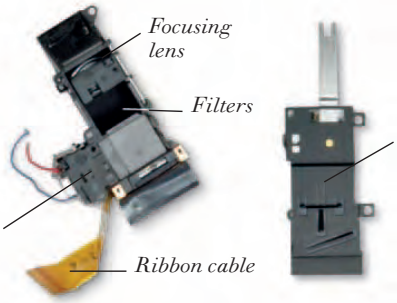
CHROMED PLASTIC SIDE COVER

REAR CASE

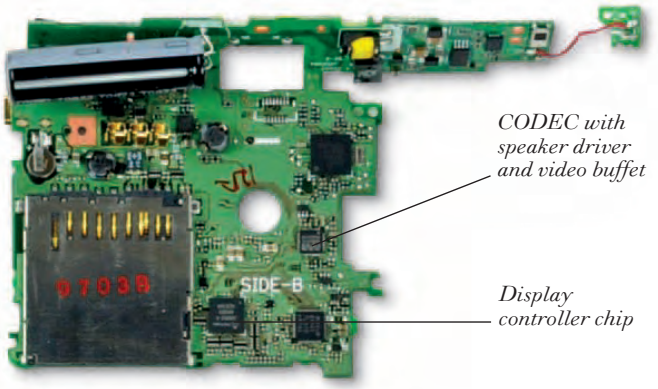
SPEAKER ASSEMBLY

COMPONENTS OF NIKON COOLPIX S1000PJ

TOP PANEL

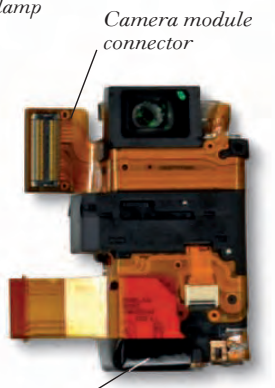


PROJECTOR ASSEMBLY



LOGIC BOARD

FRONT CASE



CAMERA MODULE

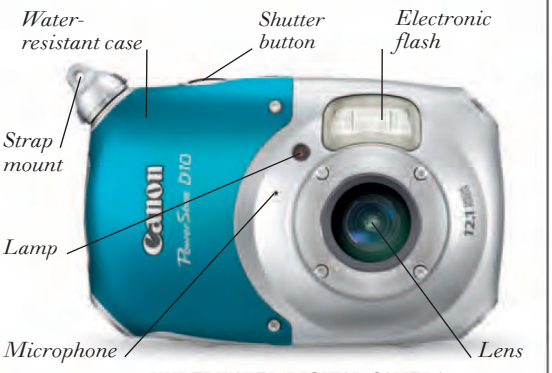
EN-EL12 RECHARGEABLE BATTERY

LENS COVER

TYPES OF DIGITAL CAMERA

DIGITAL SLR

DIGITAL CAMERA WITH INTERCHANGEABLE LENS



UNDERWATER DIGITAL CAMERA

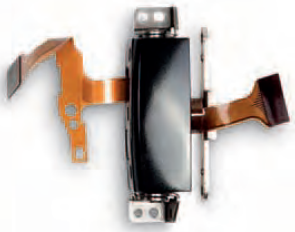
3-D DIGITAL CAMERA

Digital video camera

A VIDEO CAMERA, OR CAMCORDER, records a scene as a sequence of 25 or 30 still images per second, along with sound. It comprises a video camera to capture light from the scene, a viewfinder through which the scene may be viewed, a screen on which the recorded scene may be viewed, a charge-coupled device (CCD) to convert the visual data into an electric signal, and a means of storing the signal. Digital video cameras convert the signal into digital form—a series of separate measurements of the initial analogue (continuously varying) signal. They record the digital signal, usually on a chip or hard disk. Video cameras often have a slot where a memory card can be inserted to expand the memory and store longer recordings or more still pictures.

COMPONENTS OF A JVC EVERIO VIDEO CAMERA

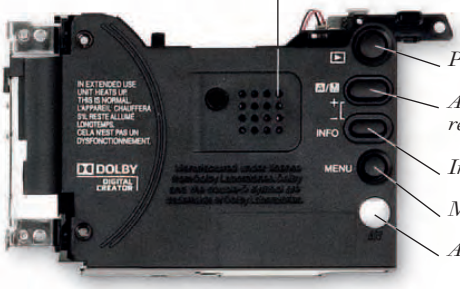
MONITOR SHELL



MONITOR MOUNT

MONITOR FRAME

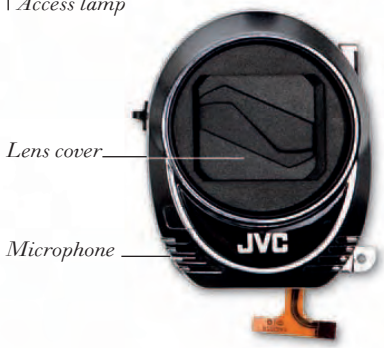
MONITOR SCREEN



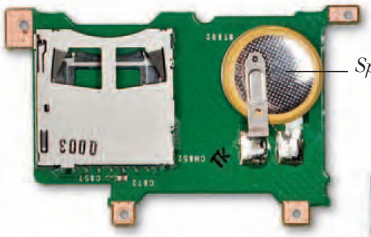
LEFT SIDE

TOP VIEW

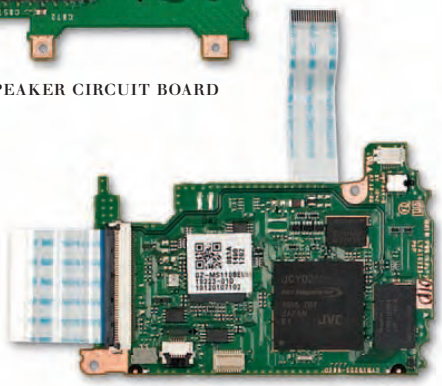
LEFT OUTER SHELL



LENS COVER ASSEMBLY

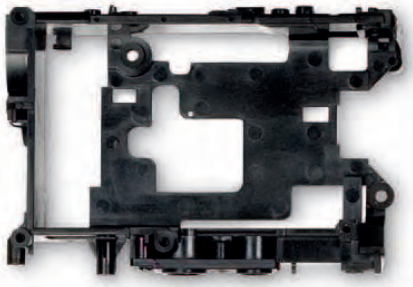


SPEAKER CIRCUIT BOARD



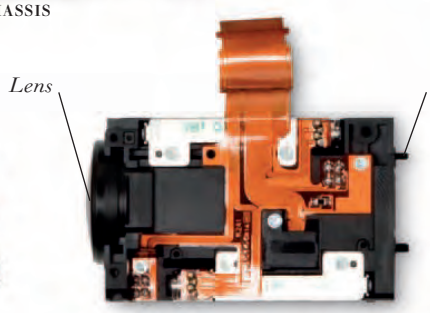
MOTHERBOARD

REAR VIEW



CHASSIS

RIGHT OUTER SHELL

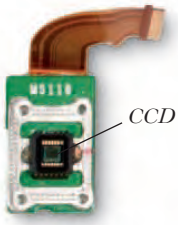


LENS UNIT

LENS UNIT MOUNT

GRIP BELT FASTENER

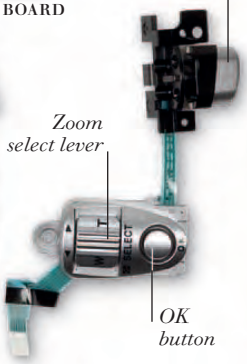
GRIP BELT



SENSOR BOARD

SDHC CARD

REAR PANEL



CONTROL UNIT

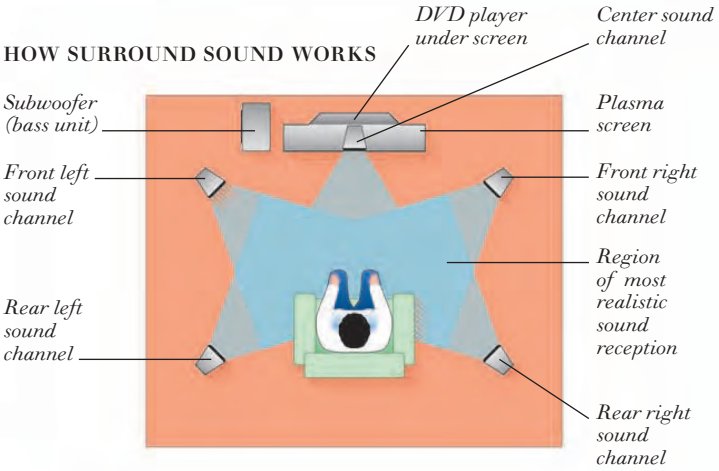
RECHARGEABLE BATTERY

Home cinema

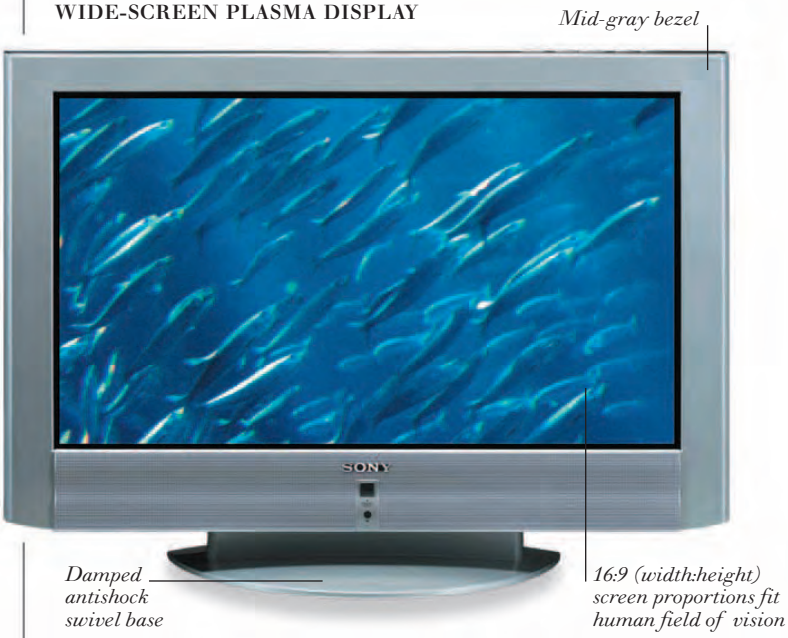
HOME CINEMA REPLICATES a real "movie theater" using pictures displayed on a high-quality widescreen television set, such as a plasma TV, and surround sound from strategically sited loudspeakers. The source for sound and vision is a DVD (Digital Versatile Disc). Its player uses standard CD (Compact Disc) digital technology, but with a higher density of laser-read microscopic pits—more than 20 billion such pits in multilevel spiral tracks that, stretched out, would extend nearly 25 miles (40km). Blu-ray is a high-quality DVD system that fits much more data on its disc than standard DVDs, allowing High Definition video files to be stored. It is hard for the human ear to discern the direction of low-pitched sounds, so these emanate from a central bass speaker, often built into or below the screen unit. High-pitched sounds, the direction of which is easier to detect, emanate from mid- and high-frequency speakers positioned around the viewer. Plasma screens use fluorescent tube ("strip-light") technology. Tiny three-cell pixels, each about one millimeter across, contain red, green, and blue phosphor chemicals and a gas mix. Where electric pulses coincide for a split second in the crisscross matrix of wire electrodes, the gas energizes and emits ultraviolet light, which in turn makes the phosphor glow.

BLU-RAY PLAYER

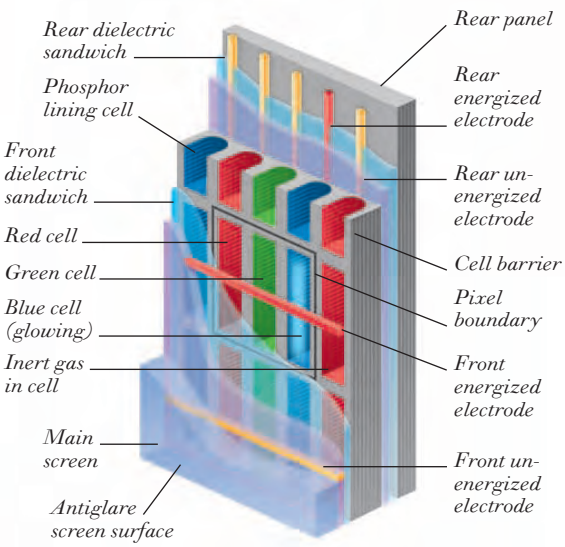
HOW SURROUND SOUND WORKS

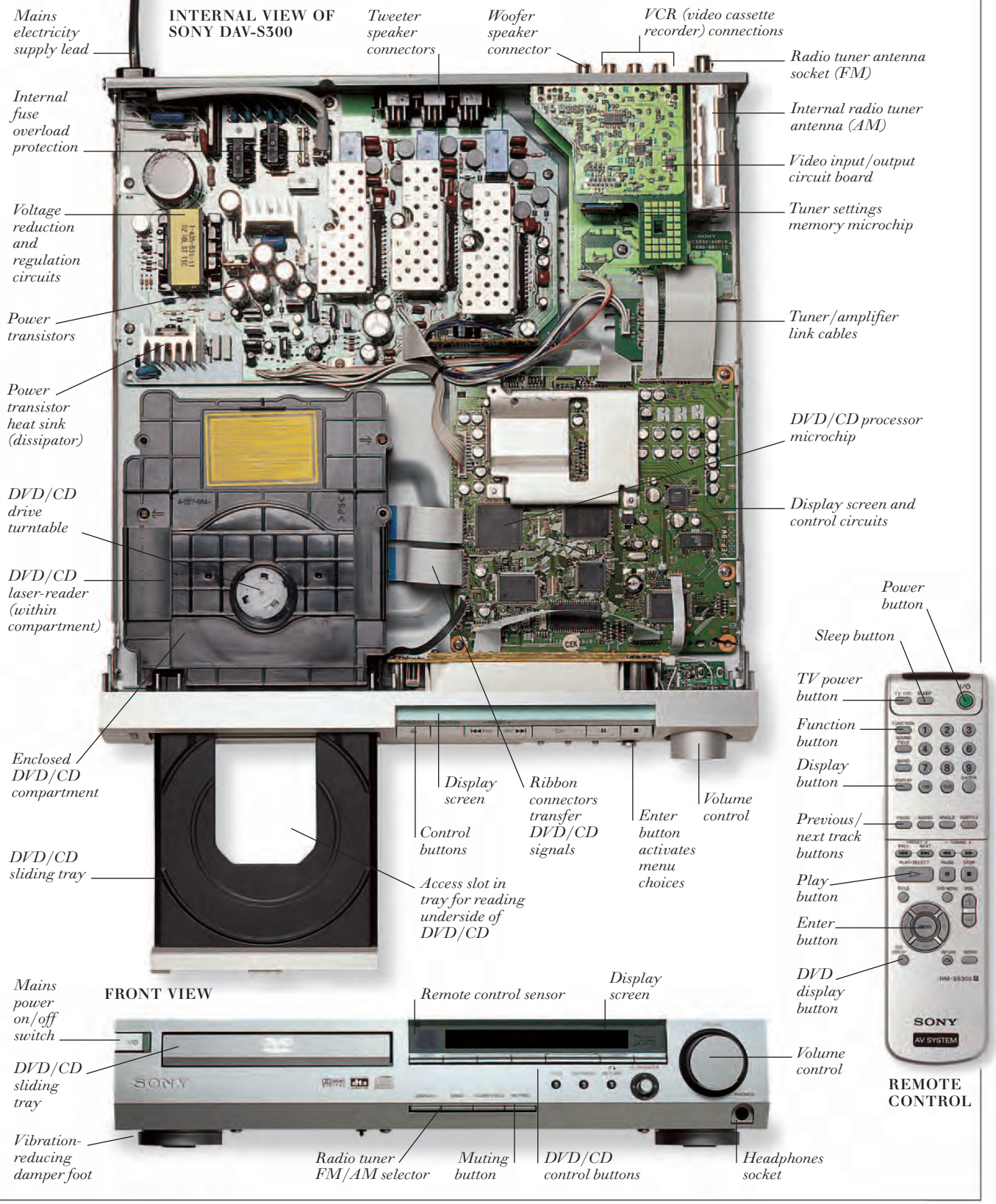


WIDE-SCREEN PLASMA DISPLAY



HOW A PLASMA SCREEN WORKS



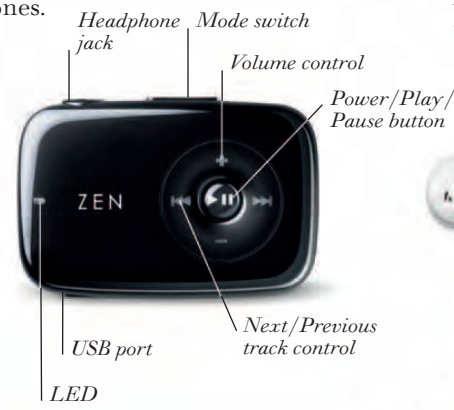

INTERNAL VIEW OF SONY DAV-S300
Mains electricity supply lead
Tweeter speaker connectors
Woofer speaker connector
VCR (video cassette recorder) connections
Radio tuner antenna socket (FM)
Internal radio tuner antenna (AM)
Internal fuse overload protection
Video input/output circuit board
Voltage reduction and regulation circuits
Tuner settings memory microchip
Power transistors
Tuner/amplifier link cables
Power transistor heat sink (dissipator)
DVD/CD processor microchip
DVD/CD drive turntable
Display screen and control circuits
DVD/CD laser-reader (within compartment)
Enclosed DVD/CD compartment
Display screen
Ribbon connectors transfer DVD/CD signals
Volume control
Control buttons
Enter button activates menu choices
DVD/CD sliding tray
Access slot in tray for reading underside of DVD/CD
Power button
Sleep button
TV power button
Function button
Display button
Previous/next track buttons
Play button
Enter button
DVD display button
Volume control
REMOTE CONTROL
FRONT VIEW
Mains power on/off switch
Remote control sensor
Display screen
DVD/CD sliding tray
Vibration-reducing damper foot
Radio tuner FM/AM selector
Muting button
DVD/CD control buttons
Headphones socket

Personal music and video

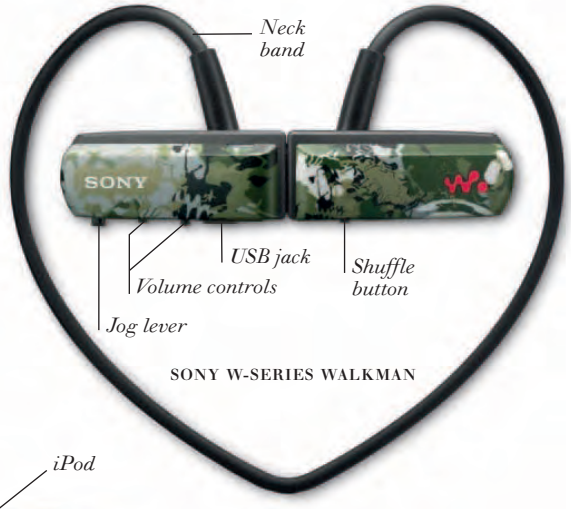
THE FIRST BATTERY-DRIVEN PORTABLE source of sound and music was the transistor radio of the 1950s. In the 1970s, the magnetic audio cassette tape allowed recordings to be played on portable tape players. Also, new metal alloys permitted the tiny but high-power magnets needed for lightweight earphones. In the 1980s, compact discs brought music into the digital era. Sony's MD, or minidisc, introduced re-recordable CDs that used magnetic and optical technology. From the mid 1990s, music could be stored in all-electronic digital form in a microchip, usually in the MP3 file format. These files can be transferred between devices and via the Internet. Today, a variety of portable media gadgets can record, play, and store video, photographs, and music in electronic form.

MP3 PLAYERS

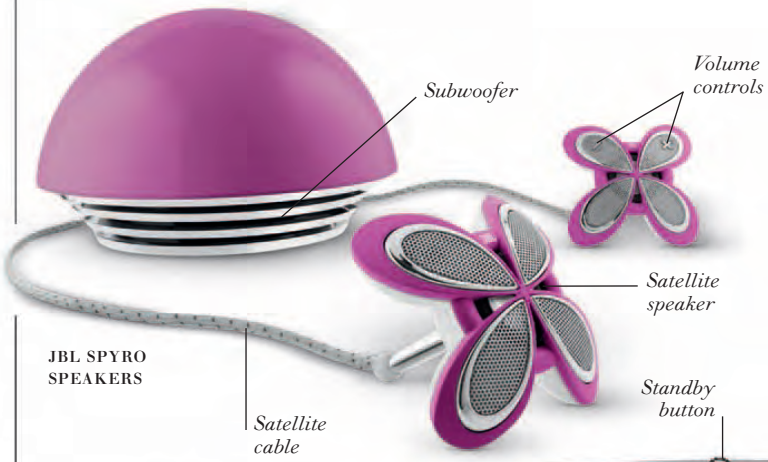
SONY B-SERIES MP3 PLAYER



CREATIVE ZEN STONE



SONY W-SERIES WALKMAN



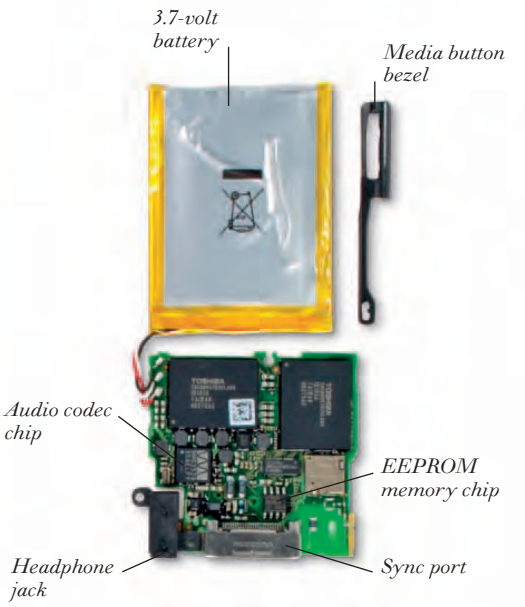
JBL SPYRO SPEAKERS

ZEPPELIN IPOD SPEAKER DOCK

COMPONENTS OF MICROSOFT ZUNE HD

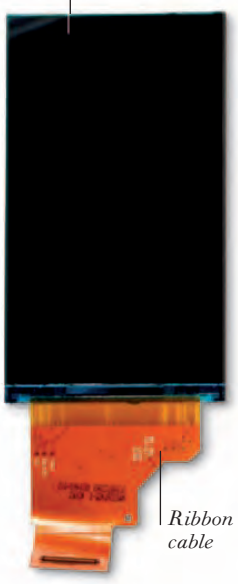
FRONT PANEL

CHASSIS



LOGIC BOARD

MICROSOFT ZUNE HD



DISPLAY

REAR VIEW

SIDE VIEW

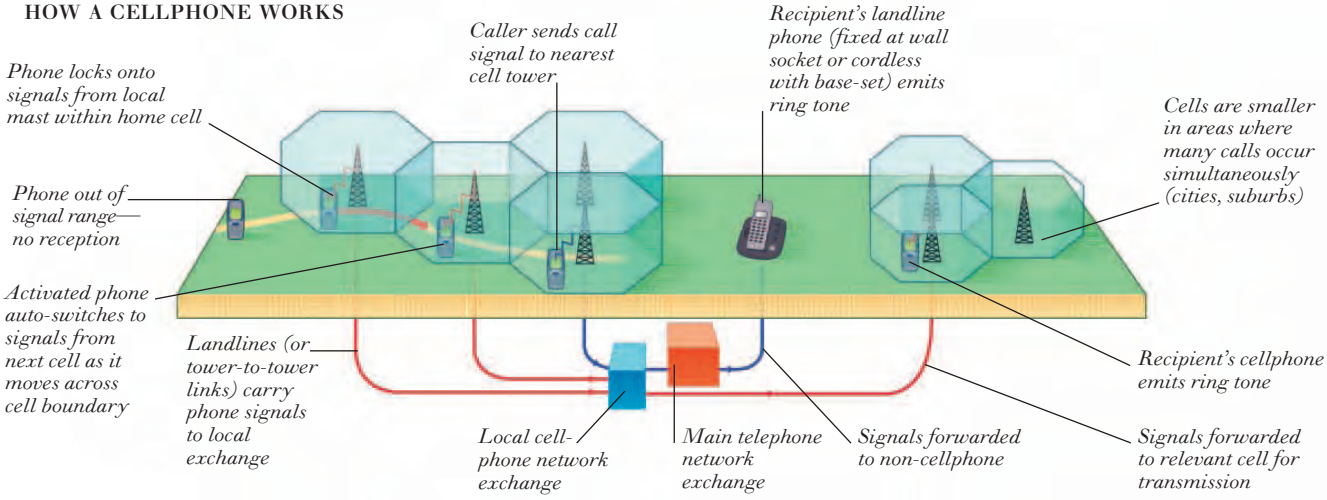
Cellphones

IN THE EARLY 1990s, THE CELLPHONE (or mobile phone) was a rare luxury, but in recent years it has outsold almost every other electrical gadget—as a professional tool, domestic convenience, and even a fashion accessory. Cellphones have also generally shrunk in size, due to improvements in rechargeable batteries, which now store more electricity for longer in a smaller package, and to smaller, more efficient electronics that use less electricity. A "cellphone" is basically a low-power radio receiver-transmitter, plus a tiny microphone to convert sounds into electrical signals, and a small speaker that does the reverse. When the cellphone is activated, it sends out a radio signal that is answered by nearby mast transmitter-receivers. The phone locks onto the clearest signal and uses this while within range (the range of each transmitter is known as a cell). The phone continuously monitors signal strength and switches to an alternative transmitter when necessary. The phone's liquid crystal display (LCD) shows numbers, letters, symbols, and color pictures. Newer models have a larger screen for more complex color images, and commonly incorporate a camera, radio, and MP3 functionality. Smartphones, which are increasingly widespread, contain additional software and more may be downloaded. Smartphones typically offer internet and email access, PDA-like functions (see pp. 568–569), and may even contain GPS navigation software.

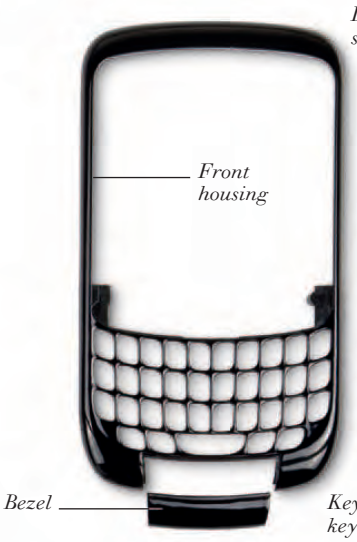
I-PHONE 4

LG OPTIMUS 2X

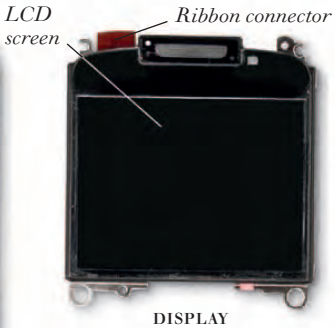
HOW A CELLPHONE WORKS



COMPONENTS OF BLACKBERRY CURVE 8520



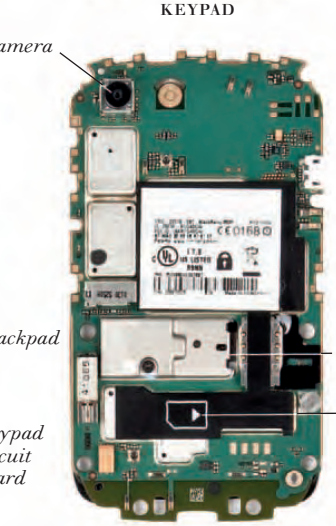
FASCIA



DISPLAY

KEYPAD

LOGIC BOARD (FRONT)

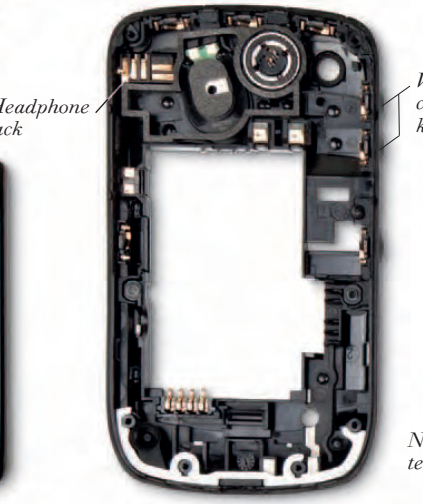


LOGIC BOARD (REAR)

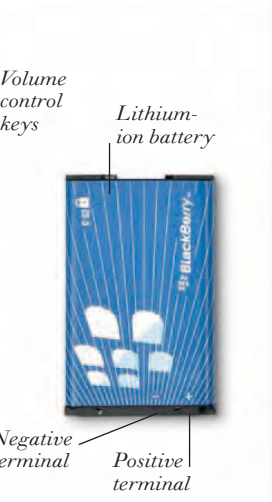
SCREEN LENS

BATTERY COVER

BLACKBERRY CURVE 8520



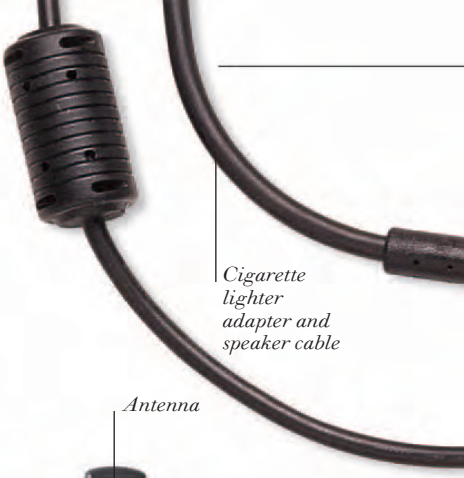
REAR HOUSING



RECHARGEABLE BATTERY

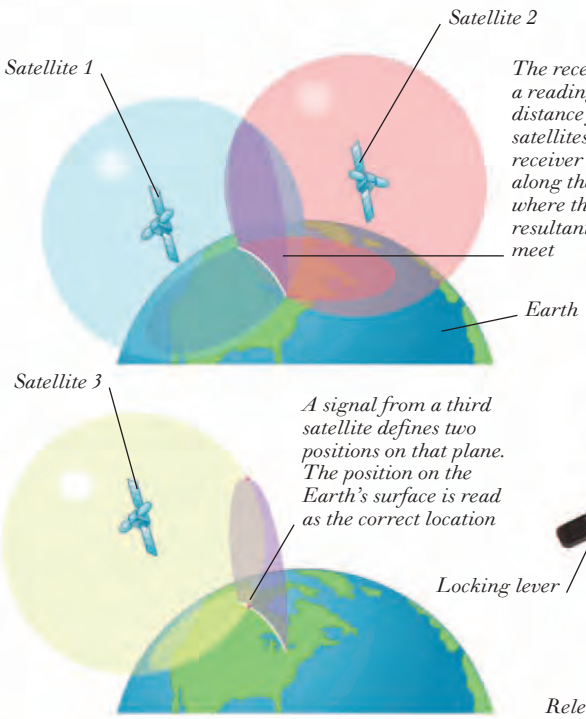
Global positioning system

THE GLOBAL POSITIONING SYSTEM (GPS) is a network of 24 navigation satellites orbiting the Earth that people can use to pinpoint their position. The satellites orbit at a height of 12,500 miles (20,000 km). A GPS receiver picks up signals from any of these satellites that are above the horizon. It uses information in each signal to work out how far away it is from the satellite. It can calculate its position on the Earth's surface when it has information from at least three satellites. A basic GPS receiver shows the latitude and longitude of its position on its screen. More advanced receivers, especially those designed for use in vehicles, show their position on a digital map. These receivers often show extra information, such as the vehicle's speed and the length of the journey. Some receivers warn drivers if they exceed the speed limit for a road and even tell drivers which traffic lane to use at the next junction. Directions are shown on the screen and also spoken by a synthesized voice.

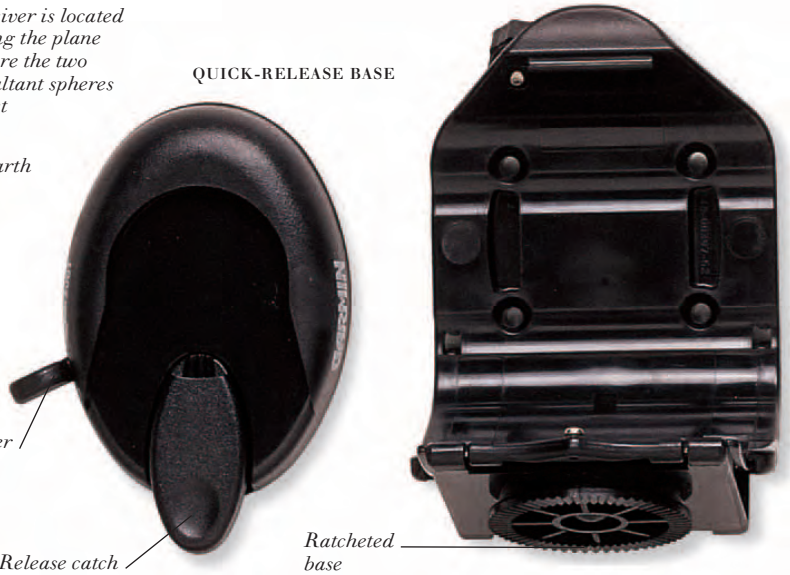


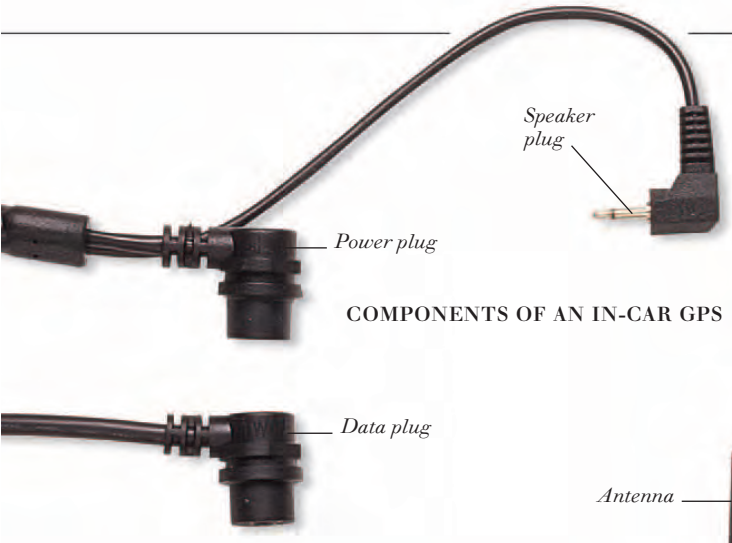
IN-CAR GPS

HOW GPS WORKS

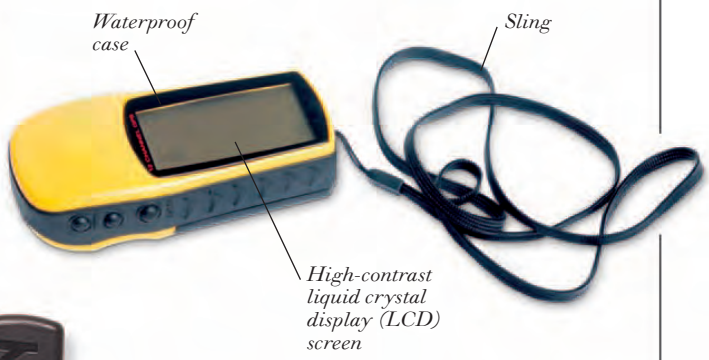


IN-CAR MOUNTING BRACKET ASSEMBLY

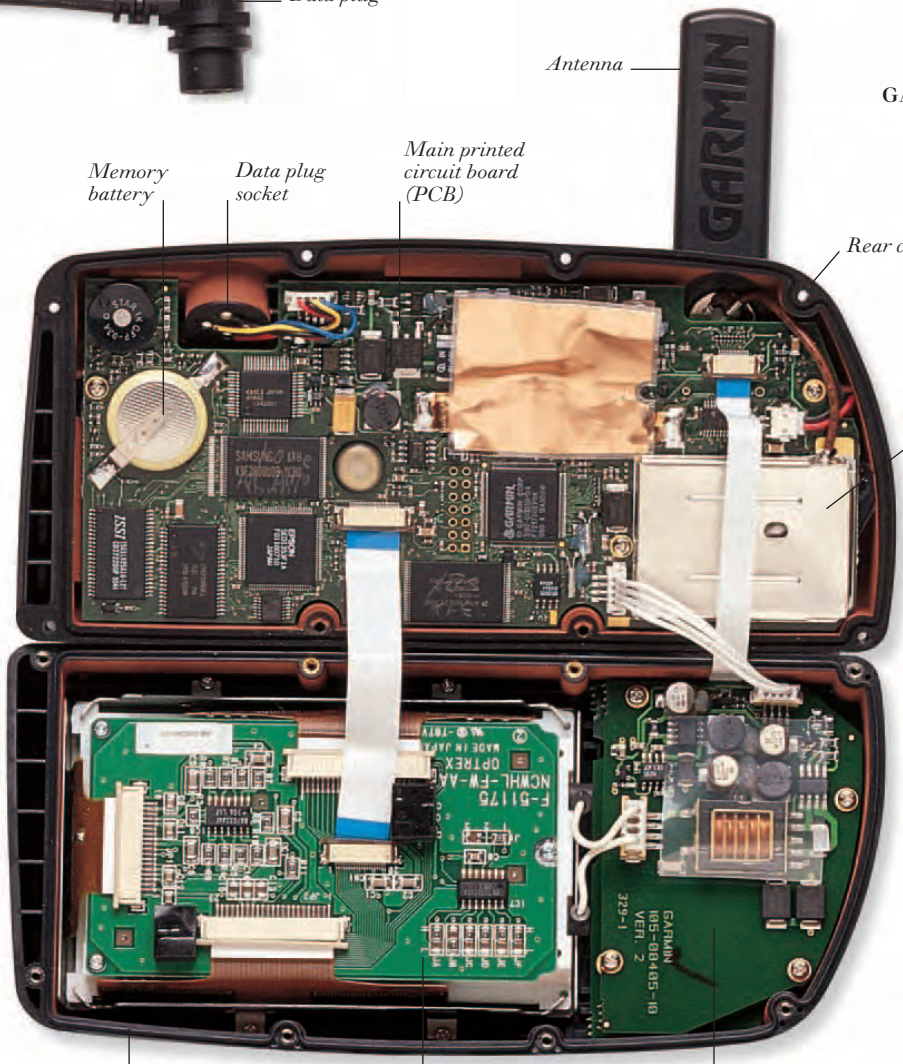




COMPONENTS OF AN IN-CAR GPS



GARMIN ETREX HANDHELD GPS



USB PROGRAMMER ASSEMBLY

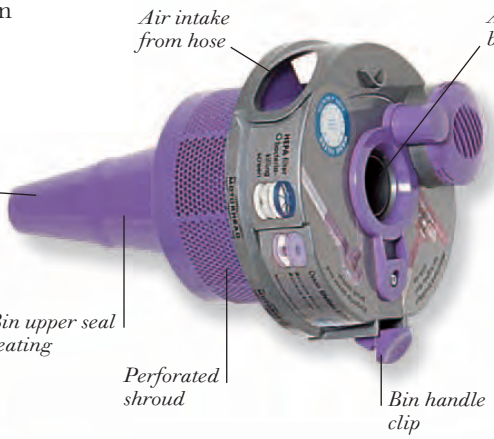
SPARE FUSES

Vacuum cleaner

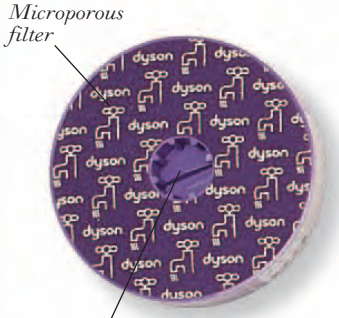
In a conventional vacuum cleaner, an electric motor spins a fan that sucks in air carrying dust and debris. The air is forced through tiny pores in a dust bag, trapping most particles. In the 1990s, James Dyson's dual cyclone "bagless" design did away with the dust bag—and the reduced airflow caused by clogging of its pores. An electrically driven fan creates a partial vacuum within the machine. This sucks air into the machine past a rotating brush that loosens dirt. The air flows into a cylinder-shaped bin. As the air whirls around the bin like a miniature storm, or cyclone, larger particle are flung outward and fall to the bottom of the bin. The air then passes through perforations into a cone-shaped inner bin and then into a series of smaller cones, spinning faster all the time and flinging smaller and smaller particle out. The nearly clean air exits the machine through microfilters that trap the tiniest particles. Some Dyson vacuum cleaners run on a large ball instead of wheels. The ball makes it easier to steer the cleaner.

DYSON DC05 MOTORHEAD

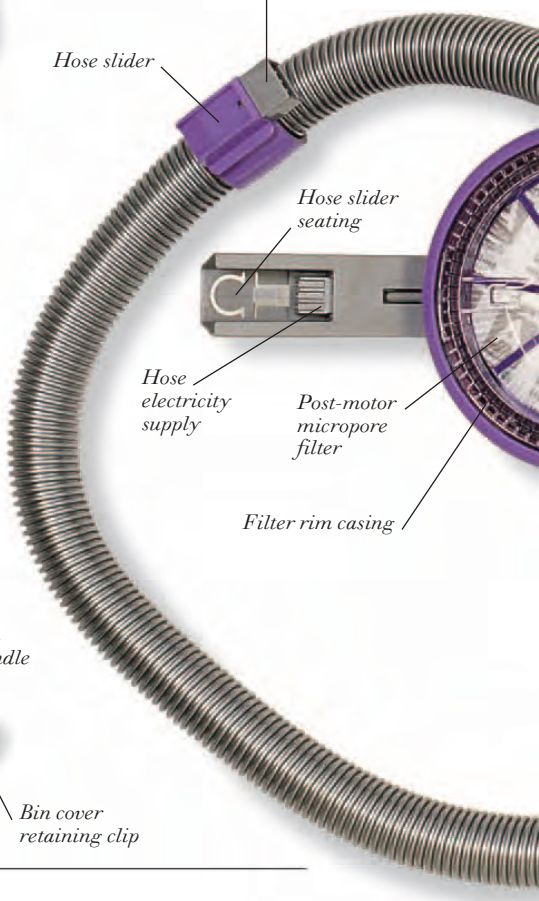
CYCLONE ASSEMBLY



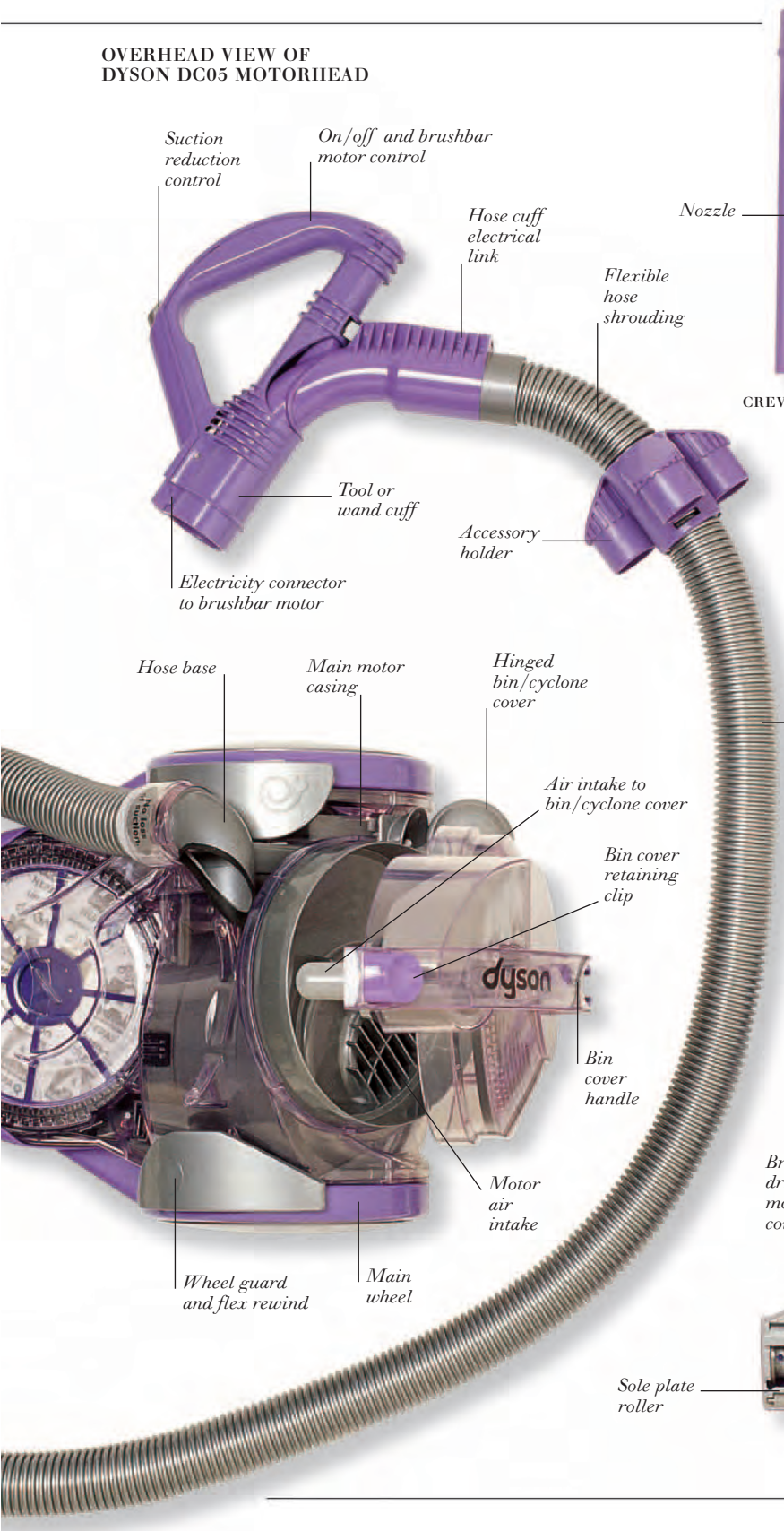
WASHABLE PRE-MOTOR FILTER



DUST COLLECTION BIN



OVERHEAD VIEW OF DYSON DC05 MOTORHEAD

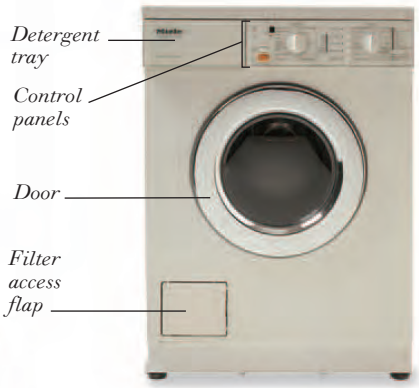


ACCESSORIES

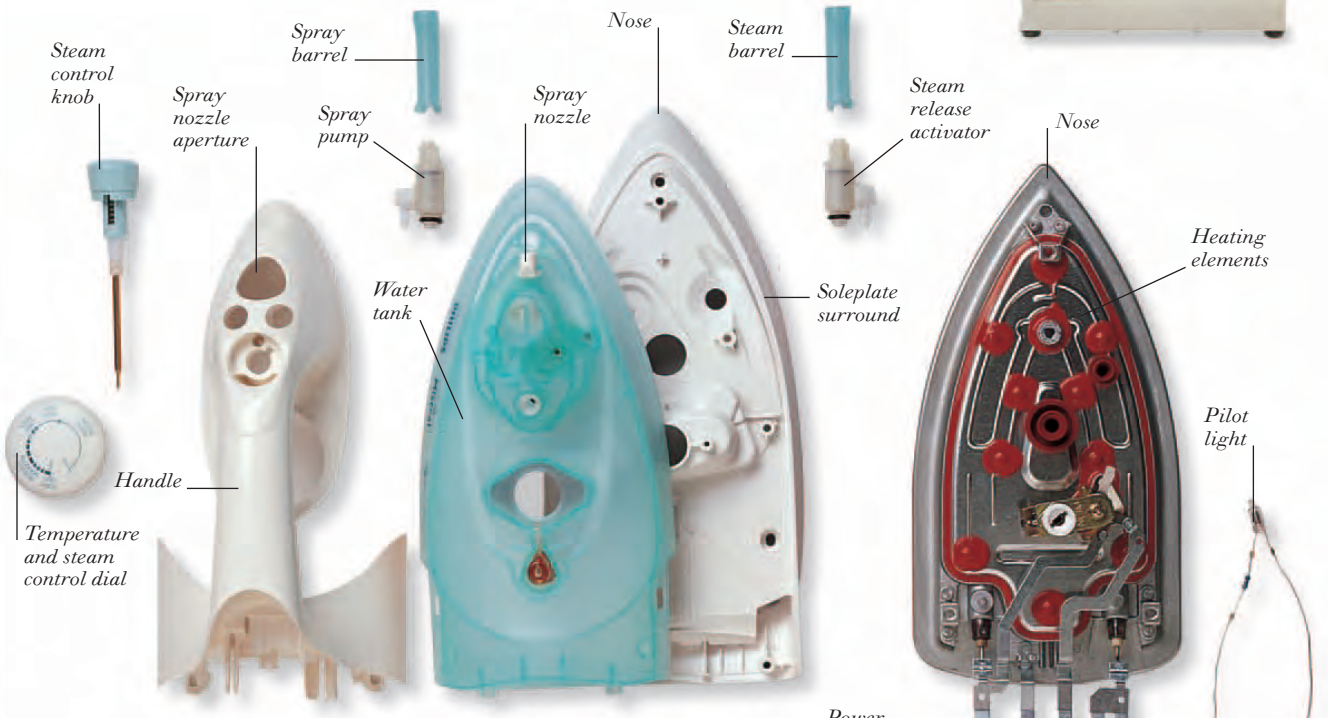
Iron and washer-dryer

IN THE DAYS BEFORE WASHING MACHINES, laundry was done by hand—washed in a barrel, squeezed in a roller-mangle, hung on a line, and smoothed with an iron heated on the stove. In the 1880s, electrically heated irons were one of the first home electrical appliances. Today's iron still applies heat, sometimes moistened with steam, to dampen and flatten garment fibers. Machines with electric heaters and motors took the strain out of washing from the 1910s. Up to the 1960s, three machines were needed to wash, spin, and dry. Now clothes are swirled in a rotating ribbed tub of hot water, then spun fast to throw off most of the water, before slowly tumbling in electrically heated air to dry—all in one appliance.

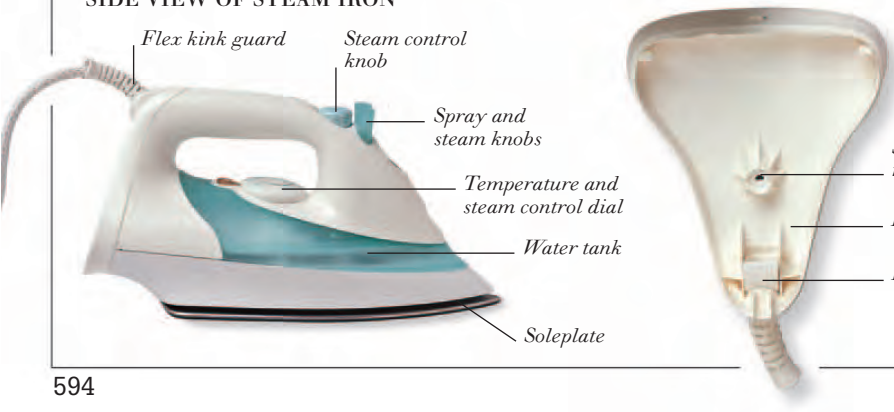
FRONT VIEW OF A MIELE WASHER-DRYER



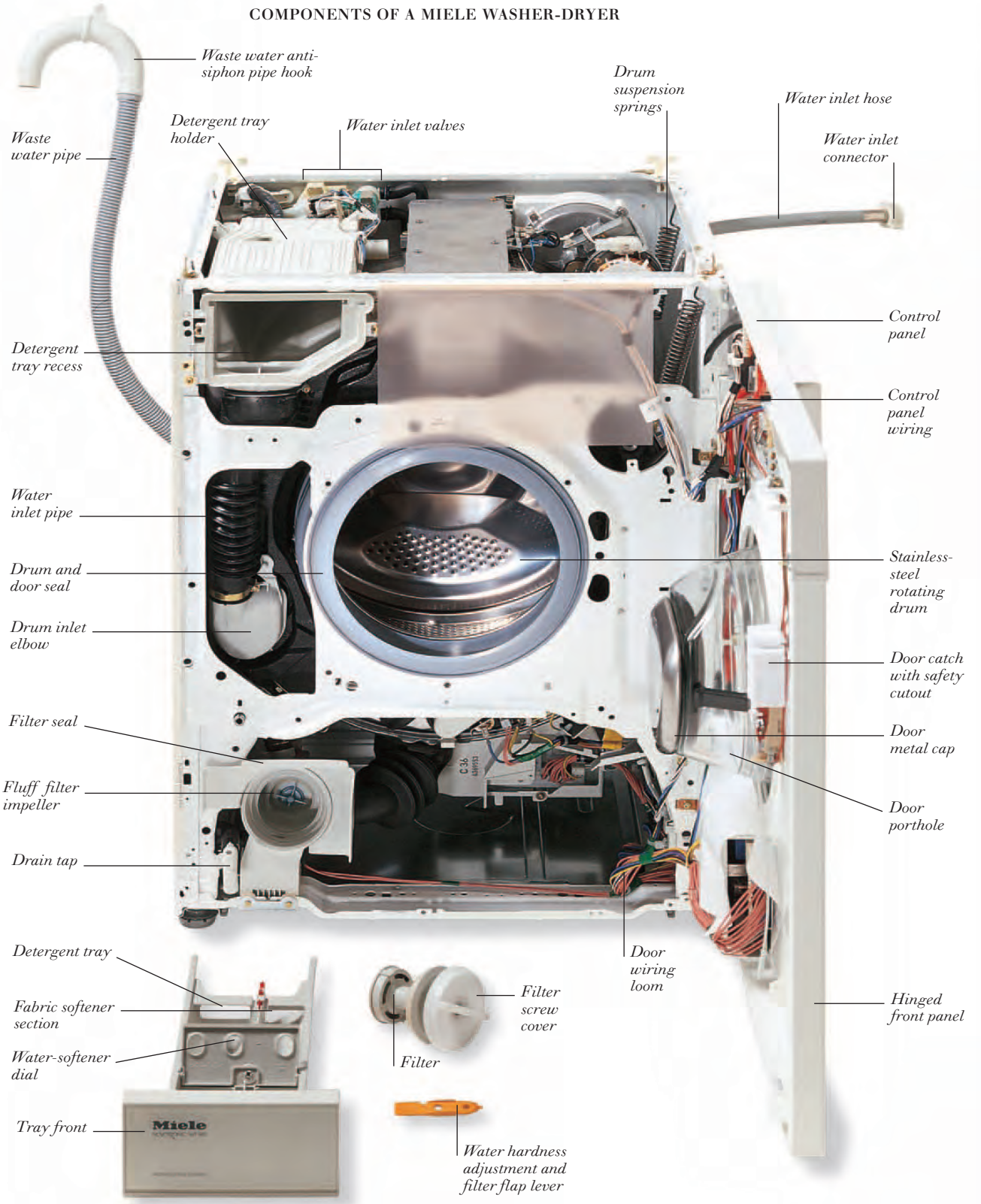
COMPONENTS OF A STEAM IRON



SIDE VIEW OF STEAM IRON



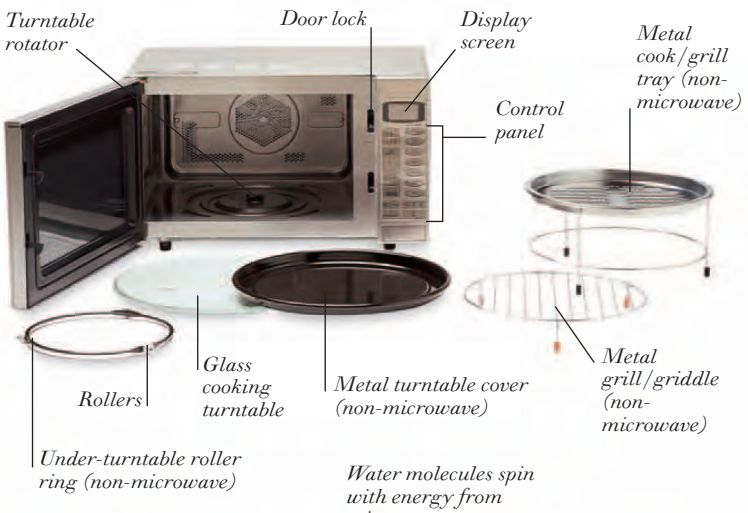
COMPONENTS OF A MIELE WASHER-DRYER



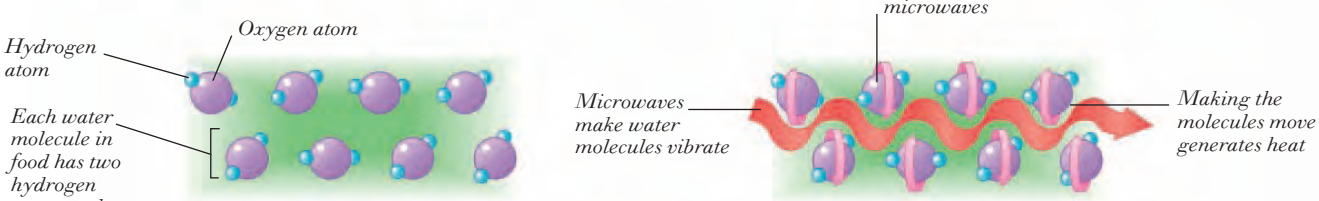
Microwave combination oven

CONVENTIONAL OVENS use electrically warmed elements or a flame to heat food. In a microwave oven heat energy is created by electromagnetic waves produced by a magnetron and led by waveguides into the oven compartment. These microwaves cannot pass through the compartment's metal casing, being reflected within and spread evenly by a fan. But they do pass through most types of plastic, ceramics, and glass. Therefore platters or containers made from these materials are suitable for use in microwave ovens. A combination oven also has conventional heating elements, to grill and "brown" in the traditional fashion, either alone or in conjunction with microwaves.

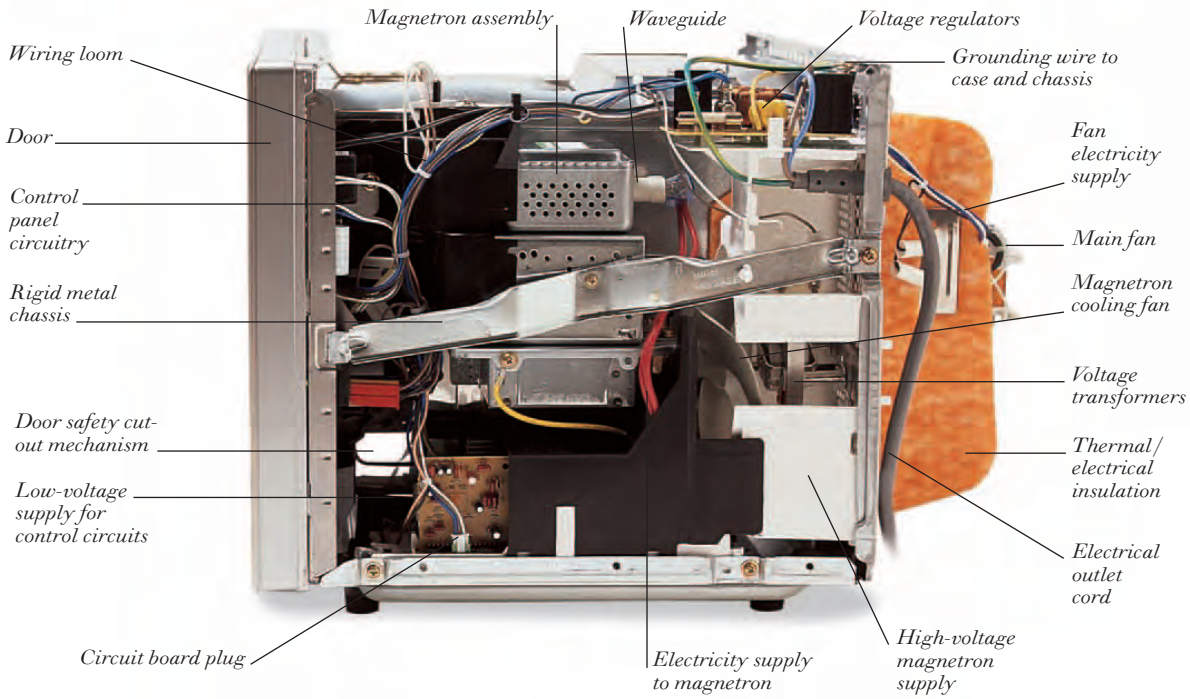
MICROWAVE COMBINATION OVEN



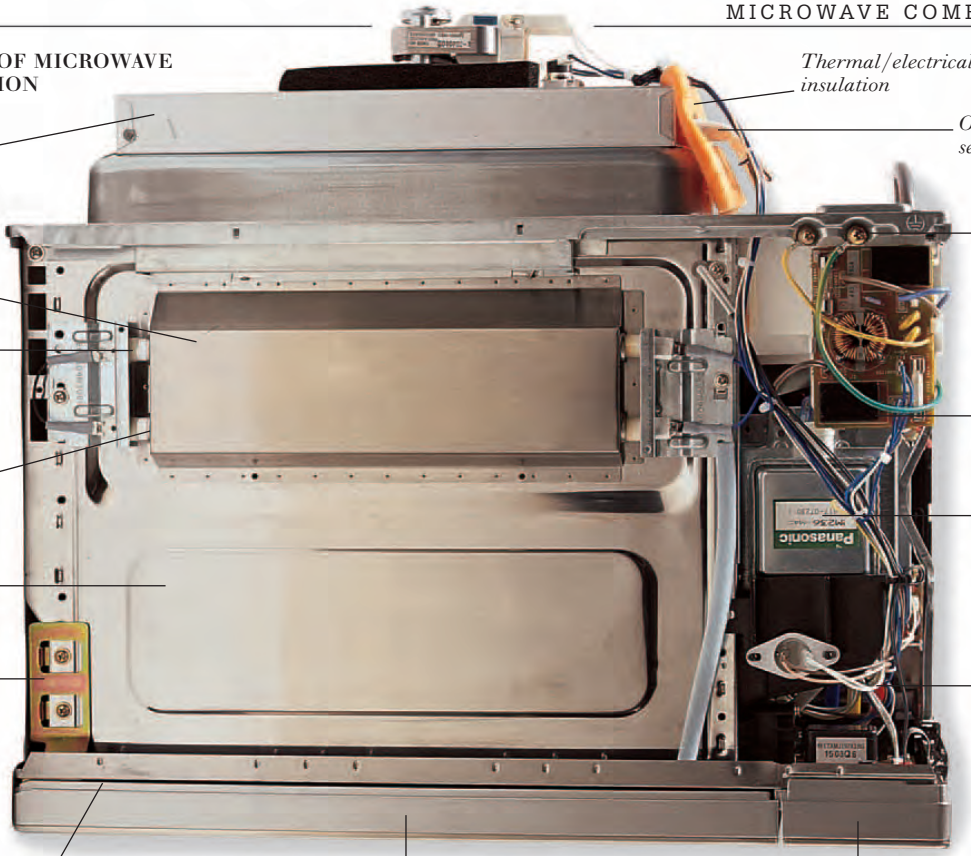
HOW MICROWAVES HEAT FOOD



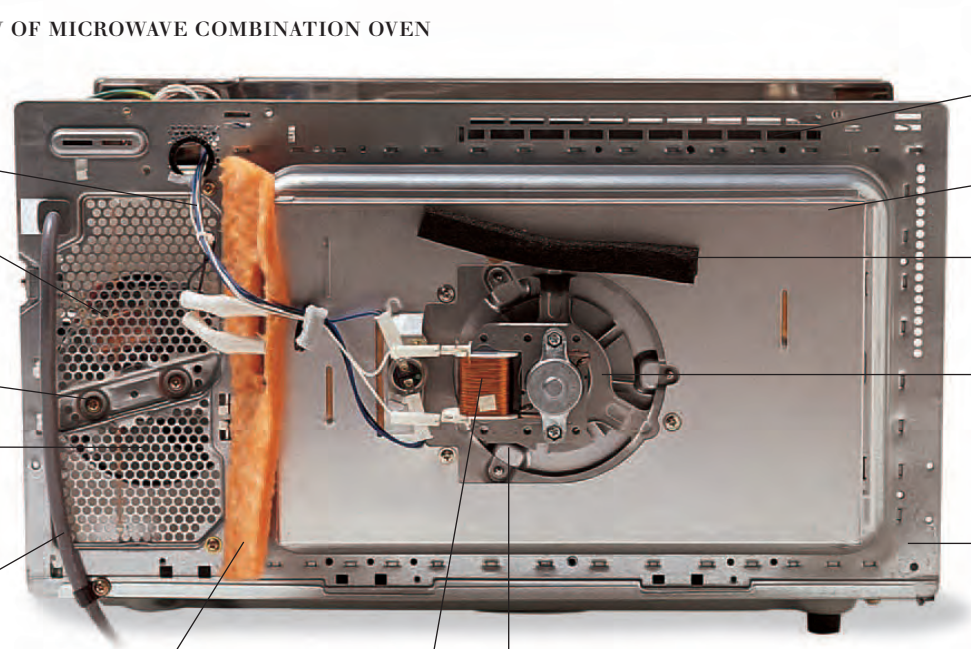
SIDE VIEW OF MICROWAVE COMBINATION OVEN



TOP VIEW OF MICROWAVE COMBINATION OVEN

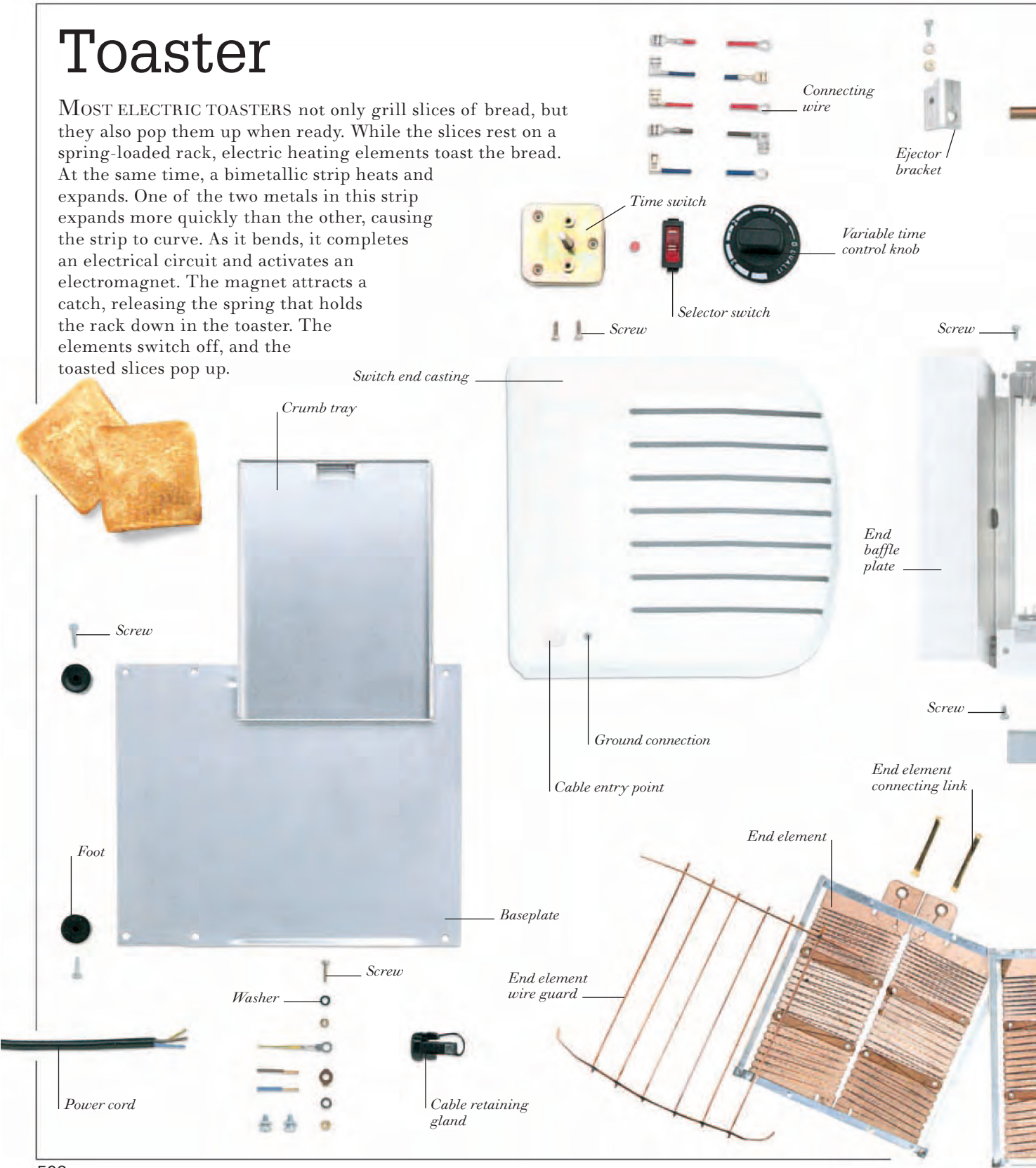


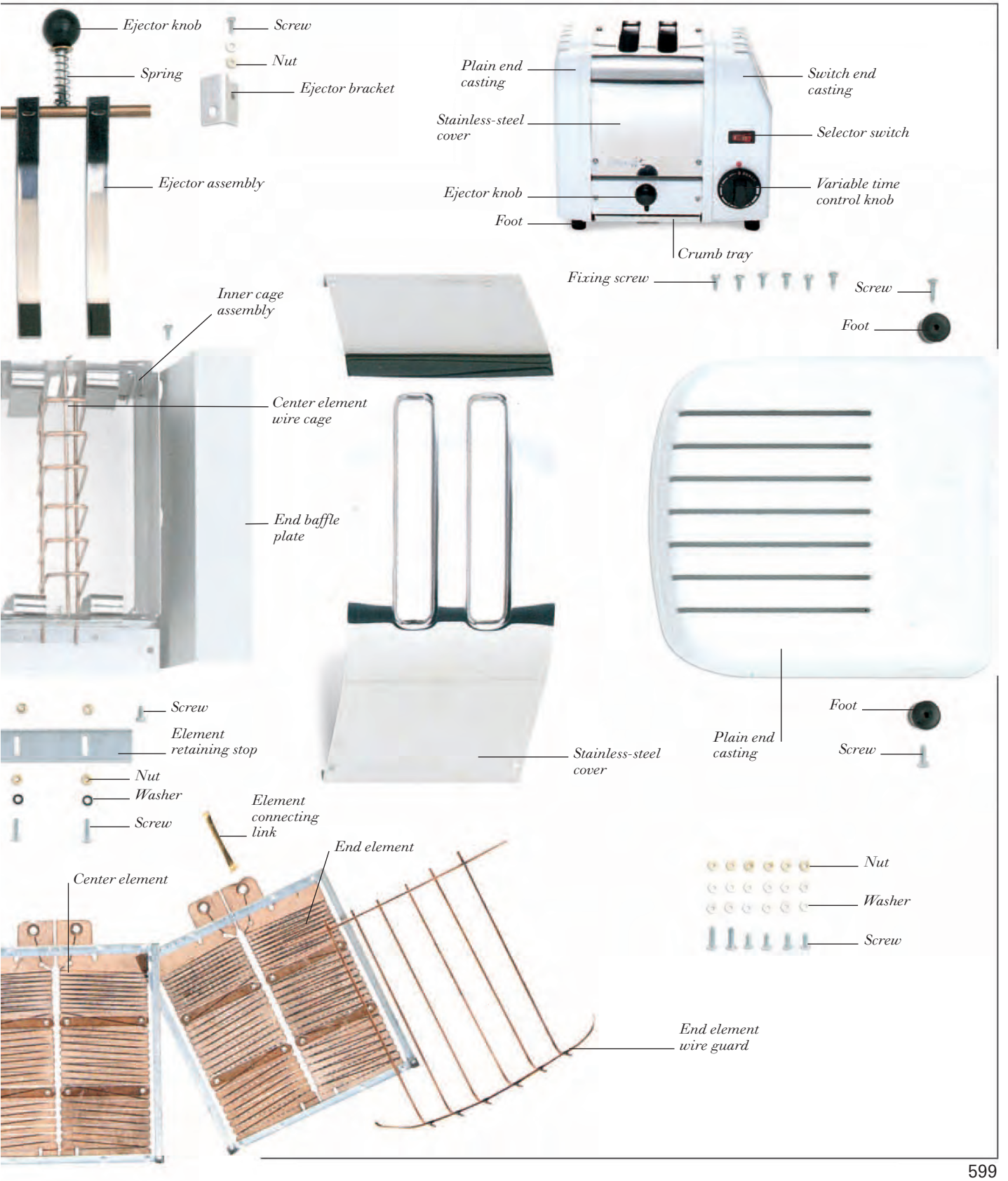
BACK VIEW OF MICROWAVE COMBINATION OVEN



Toaster

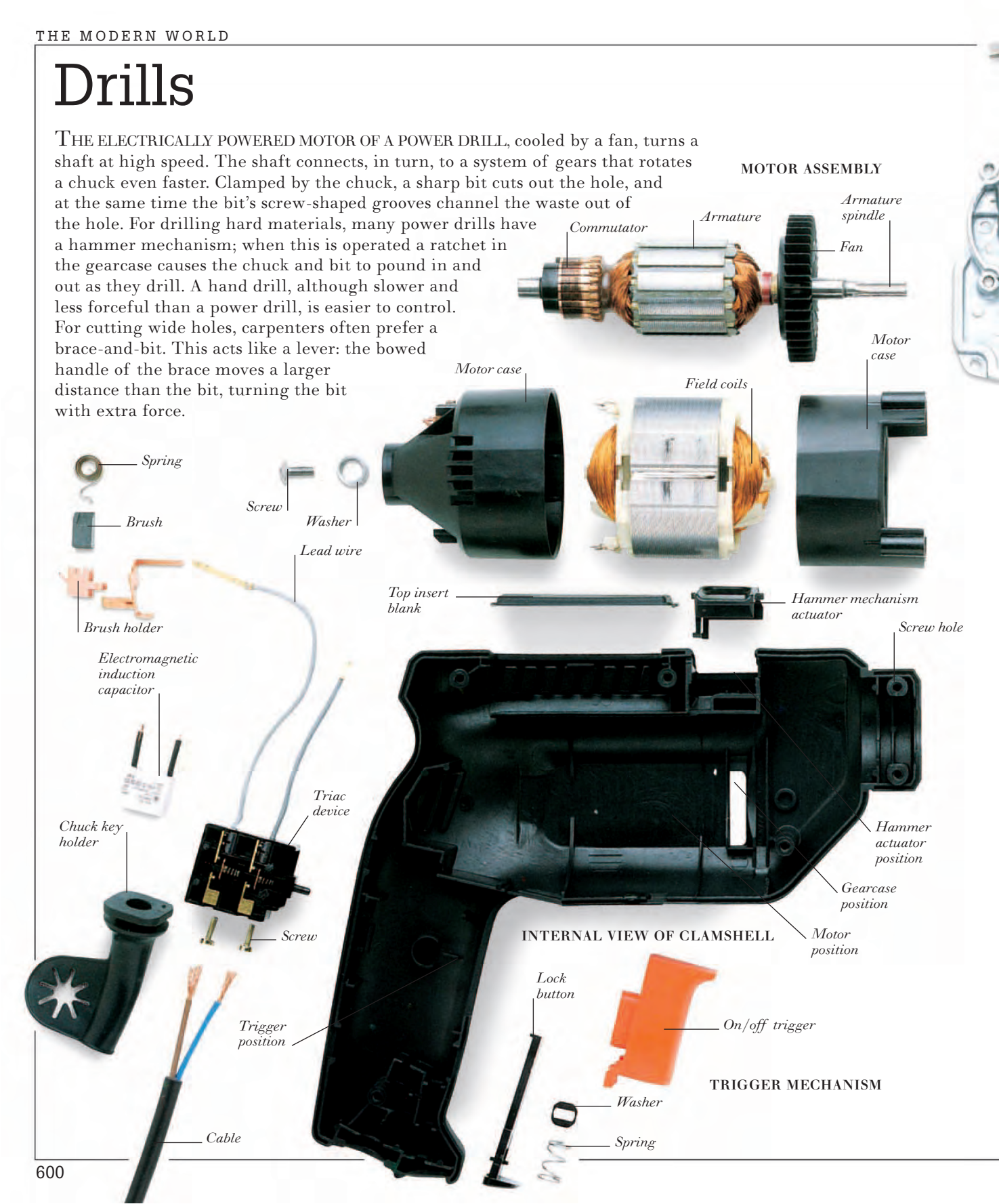
MOST ELECTRIC TOASTERS not only grill slices of bread, but they also pop them up when ready. While the slices rest on a spring-loaded rack, electric heating elements toast the bread. At the same time, a bimetallic strip heats and expands. One of the two metals in this strip expands more quickly than the other, causing the strip to curve. As it bends, it completes an electrical circuit and activates an electromagnet. The magnet attracts a catch, releasing the spring that holds the rack down in the toaster. The elements switch off, and the toasted slices pop up.

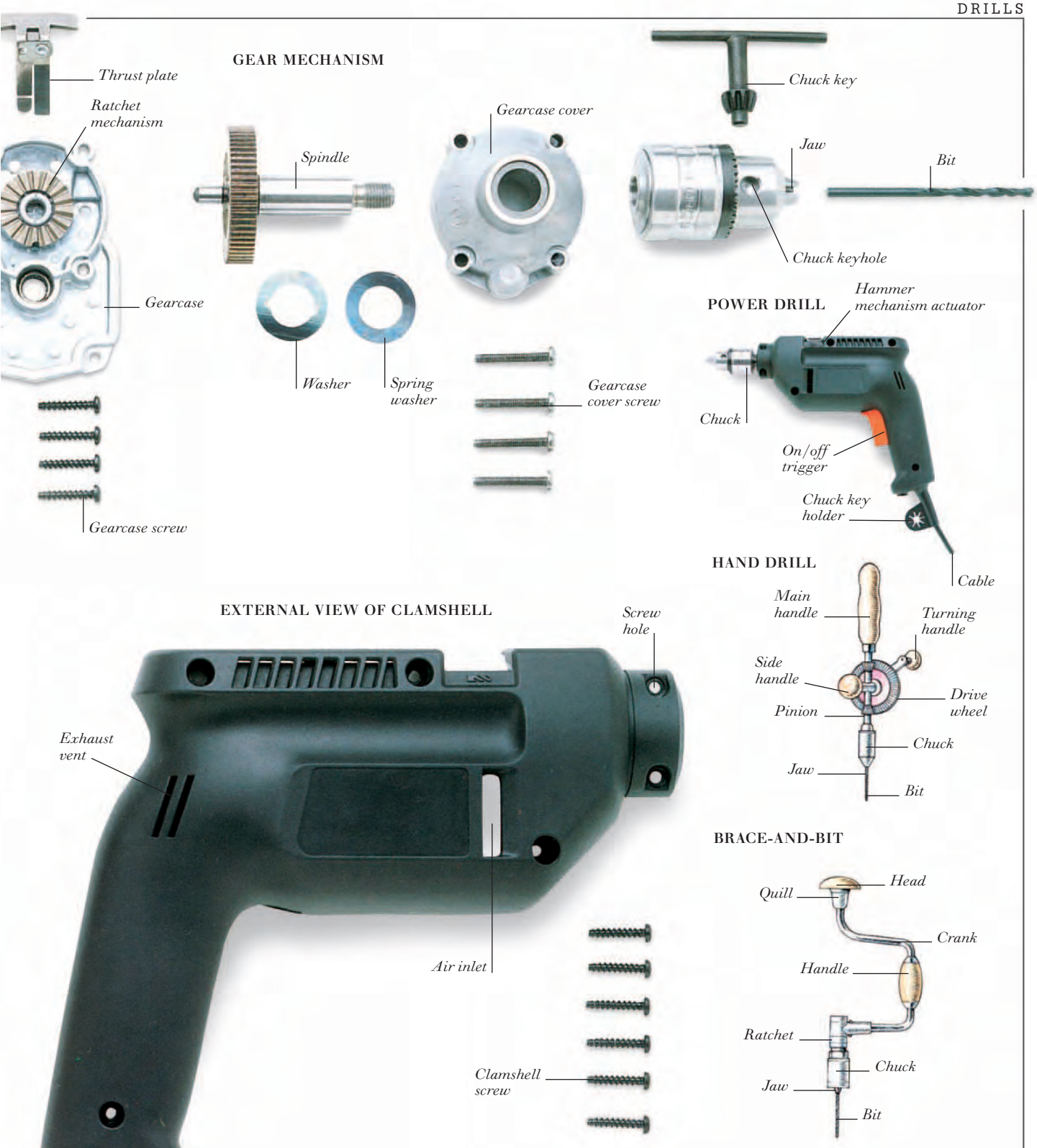



Ejector knob
Spring
Ejector assembly
Screw
Nut
Ejector bracket
Plain end casting
Stainless-steel cover
Ejector knob
Foot
Crumb tray
Switch end casting
Selector switch
Variable time control knob
Fixing screw
Screw
Foot
Inner cage assembly
Center element wire cage
End baffle plate
Stainless-steel cover
Plain end casting
Foot
Screw
Screw
Element retaining stop
Nut
Washer
Screw
Element connecting link
End element
Center element
End element wire guard
Nut
Washer
Screw

Drills

THE ELECTRICALLY POWERED MOTOR OF A POWER DRILL, cooled by a fan, turns a shaft at high speed. The shaft connects, in turn, to a system of gears that rotates a chuck even faster. Clamped by the chuck, a sharp bit cuts out the hole, and at the same time the bit's screw-shaped grooves channel the waste out of the hole. For drilling hard materials, many power drills have a hammer mechanism; when this is operated a ratchet in the gearcase causes the chuck and bit to pound in and out as they drill. A hand drill, although slower and less forceful than a power drill, is easier to control. For cutting wide holes, carpenters often prefer a brace-and-bit. This acts like a lever: the bowed handle of the brace moves a larger distance than the bit, turning the bit with extra force.

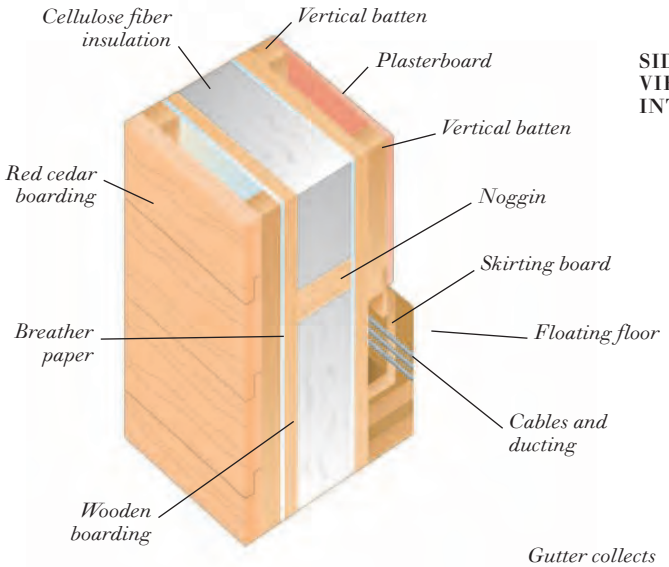



GEAR MECHANISM
Thrust plate
Ratchet mechanism
Gearcase
Gearcase screw
Spindle
Washer
Spring washer
Gearcase cover
Gearcase cover screw
Chuck key
Jaw
Bit
Chuck keyhole
POWER DRILL
Hammer mechanism actuator
Chuck
On/off trigger
Chuck key holder
Cable
HAND DRILL
Main handle
Turning handle
Side handle
Drive wheel
Pinion
Chuck
Jaw
Bit
EXTERNAL VIEW OF CLAMSHELL
Screw hole
Exhaust vent
Air inlet
Clamshell screw
BRACE-AND-BIT
Head
Quill
Crank
Handle
Ratchet
Chuck
Jaw
Bit

House of the future

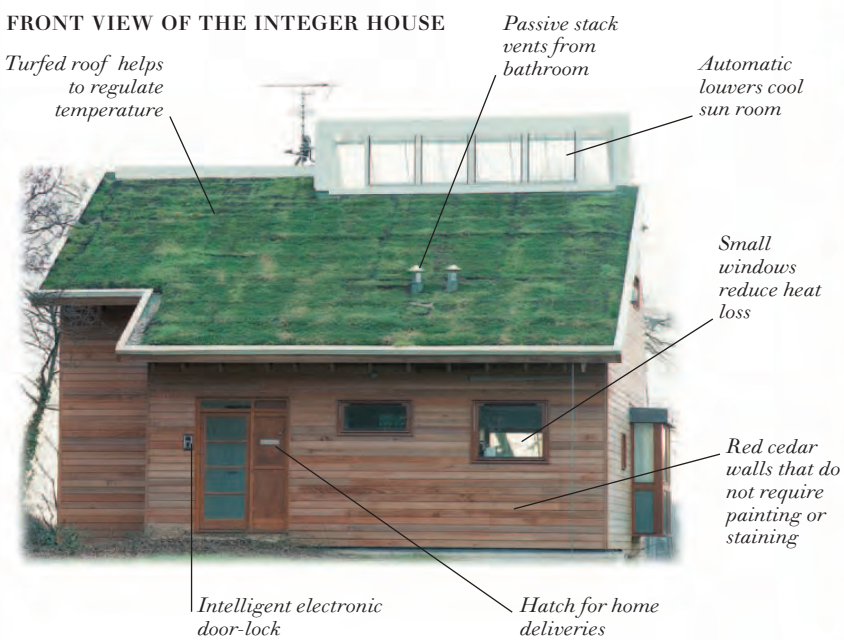
HOUSES IN THE FUTURE are likely to be more environmentally friendly and energy-efficient than older dwellings, by making better use of materials and intelligent control systems. The Integer house was designed by Cole Thompson Associates, Bree Day Partnership, and Paul Hodgkins Associates, and built in conjunction with the Building Research Establishment in the UK. One of its key features is a large sun room that warms one side of the house. Extensive use is made of recycled, natural, and renewable materials and energy. The walls are made from timber and insulated with fiber from recycled newspaper; waste water from the bathrooms is saved and used to flush the toilets; and a wind turbine and solar panels contribute some of the electricity requirements. Many elements were prefabricated off-site for ease of construction. The Integer house uses only half the energy and a third less water than a traditionally built house.

WALL CONSTRUCTION

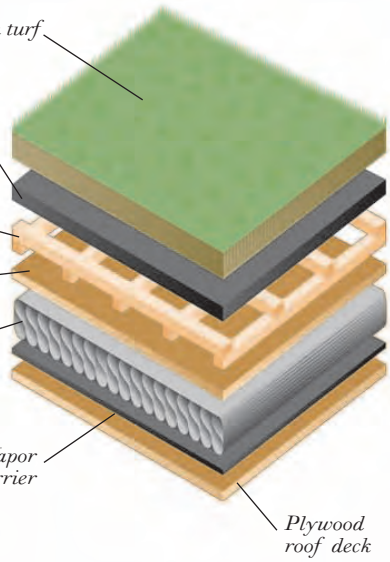


SIDE AND REAR VIEW OF THE INTEGER HOUSE

FRONT VIEW OF THE INTEGER HOUSE



ROOF CONSTRUCTION

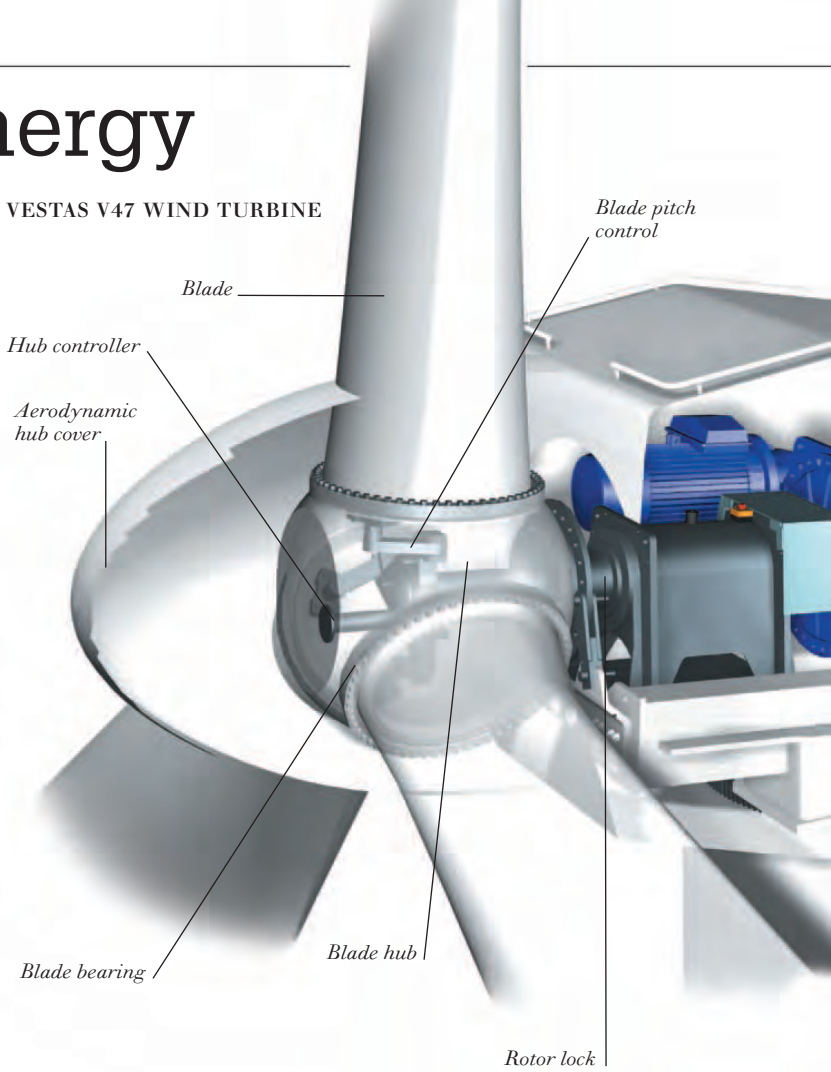


SUN ROOM INTERIOR

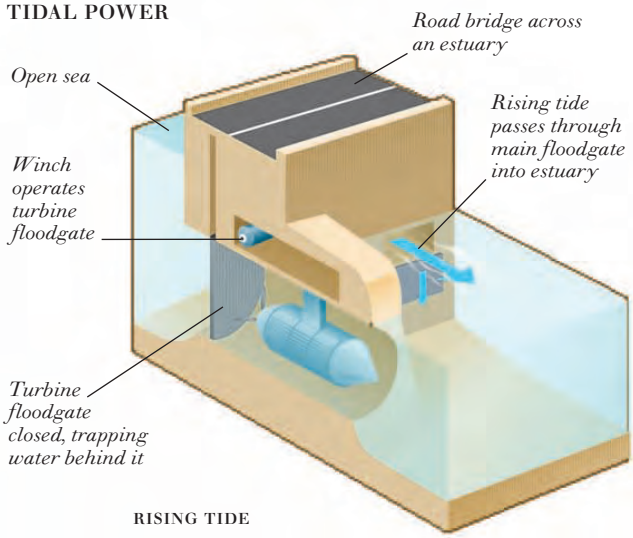
Renewable energy

RENEWABLE ENERGY COMES from sources that do not become depleted as we use the energy. When a fossil fuel such as coal is burned, it is gone forever, but a renewable source remains available no matter how much is used. The tides, waves, flowing water, sunlight, and the wind are all renewable sources of energy. Wind and water energy are captured by a device called a turbine. The turbine spins and drives an electricity generator. Energy from sunlight, or solar energy, is changed into electricity in two main ways. One uses mirrors to concentrate solar energy and magnify its heating effect which is used to change water into steam to drive turbines. Photovoltaic cells change sunlight directly into electricity. A cell is made from two layers of silicon. One gives out electrons (negative particles) and the other receives them. Sunlight knocks electrons out of atoms where the two layers meet, separating them from the positive particles. The electrons are attracted to one layer of the cell, the positive particles to the other layer. Electrons are naturally attracted to the positive particles, but to come together again, the electrons must flow out of the cell, through an external electric circuit, or load, and back to the other side of the cell, creating a charge. The cell supplies electric current for as long as light keeps falling on it.

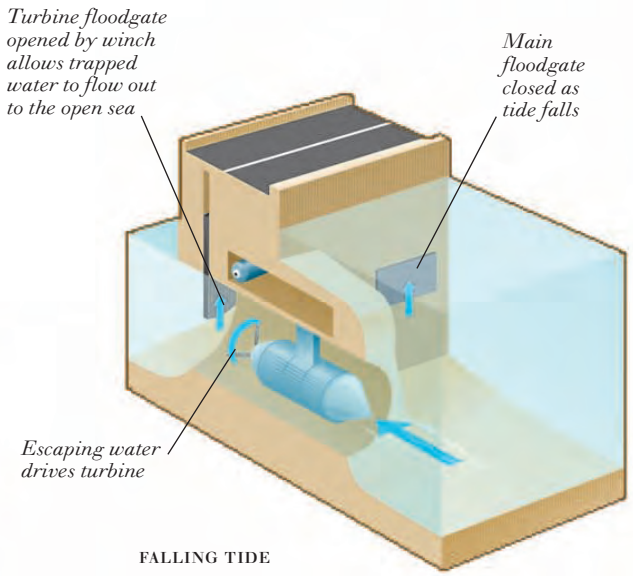
VESTAS V47 WIND TURBINE



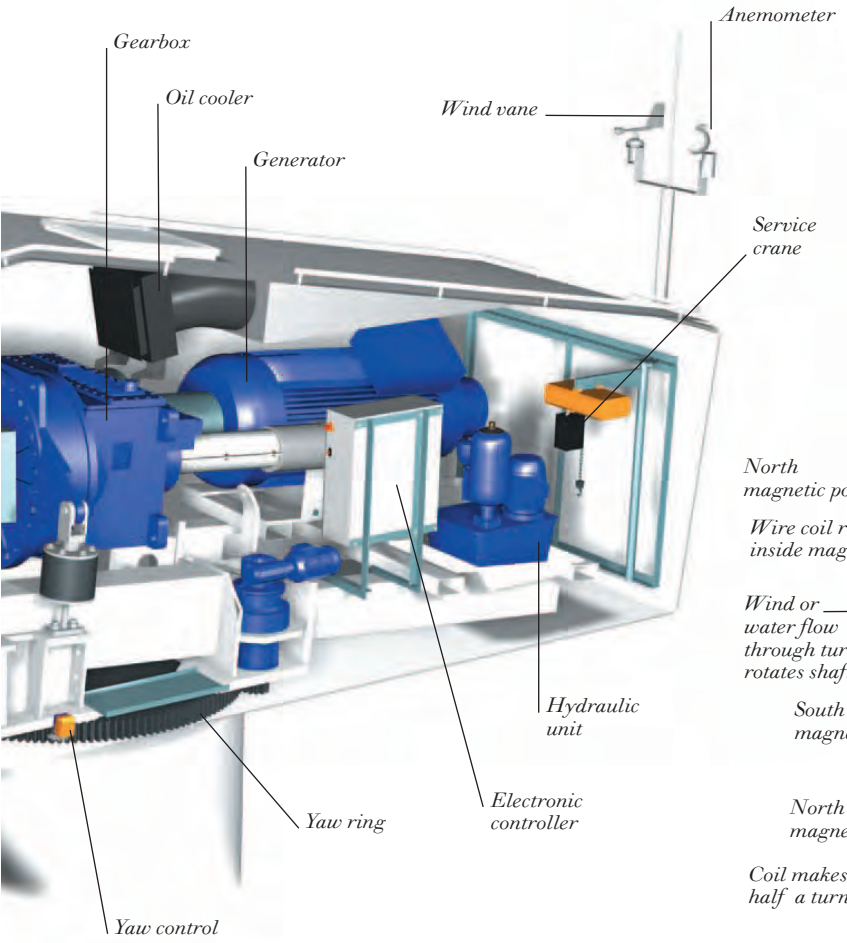
TIDAL POWER



RISING TIDE

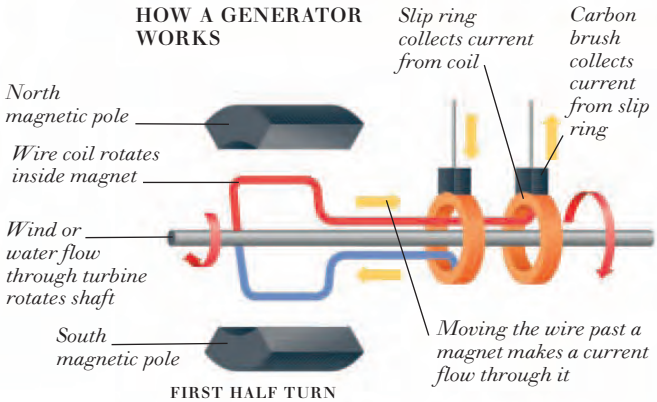


FALLING TIDE

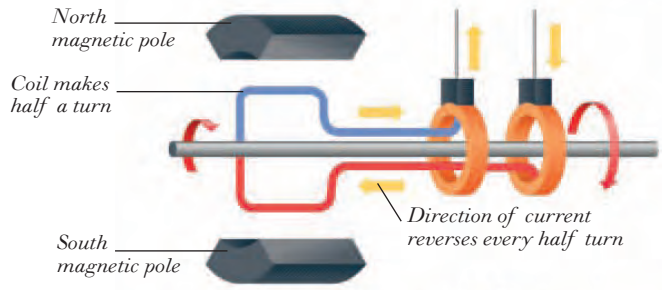


WIND TURBINES IN A WIND FARM

HOW A GENERATOR WORKS

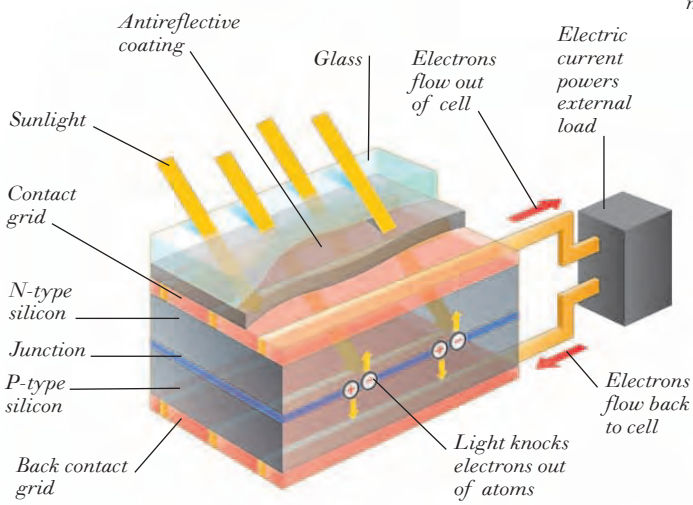


FIRST HALF TURN

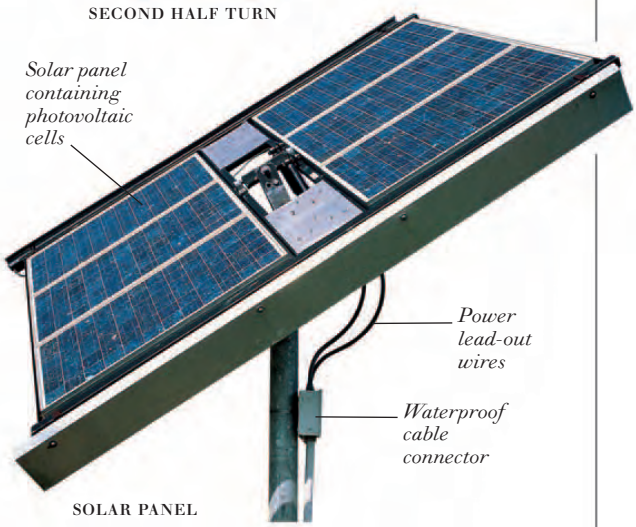


SECOND HALF TURN

SOLAR POWER



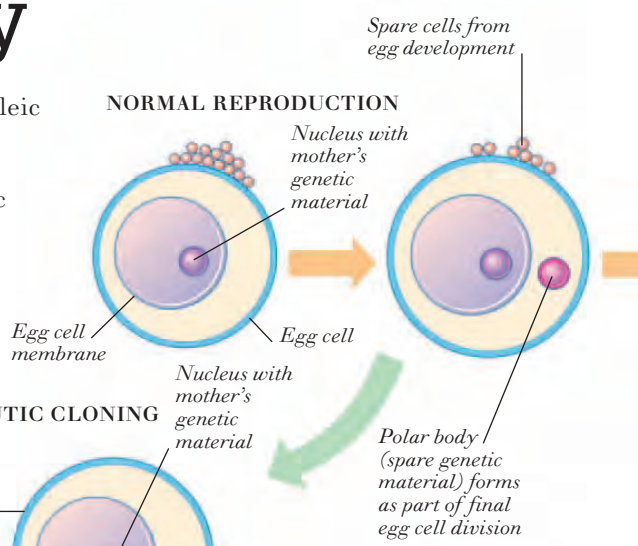
HOW A PHOTOVOLTAIC CELL WORKS

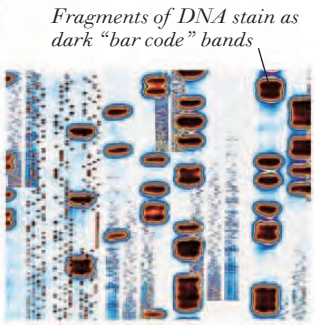


SOLAR PANEL

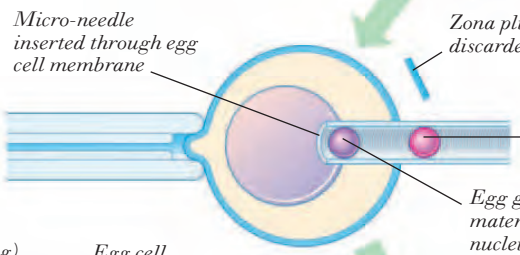
Cloning technology

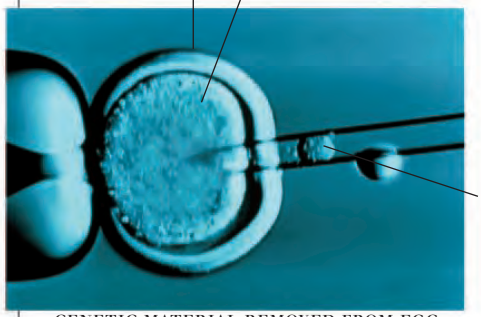
IN A LIVING CELL THE GENETIC MATERIAL DNA (deoxyribonucleic acid) contains thousands of units called genes that carry instructions for development, growth, and repair of the living creature. During normal reproduction, half the mother's genetic material contained in an egg cell joins with half the genetic material from the father carried in a sperm cell, to form a unique new genome (set of genes) for a new life. During the early stages of embryo development, the fertilized egg divides into stem cells, which have the potential to become specialized into the hundreds of cell types in a body. Through therapeutic cloning, stem cells can be produced in a laboratory. It is hoped that in the future this technology can be used to grow new tissue that can be transplanted back into the donor to treat illness, without fear of rejection—when the body recognizes a transplanted part as "foreign" because it has different genes, and tries to destroy it. In another form of cloning, performed experimentally using animals, genetic material from a donor animal has been inserted into an egg from another animal that has been emptied of its own genetic material, to produce an animal genetically identical to the donor.



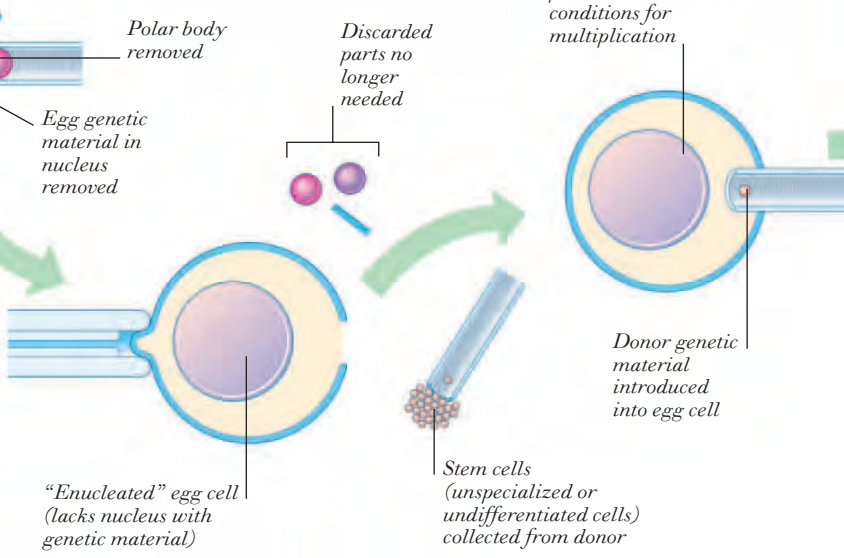


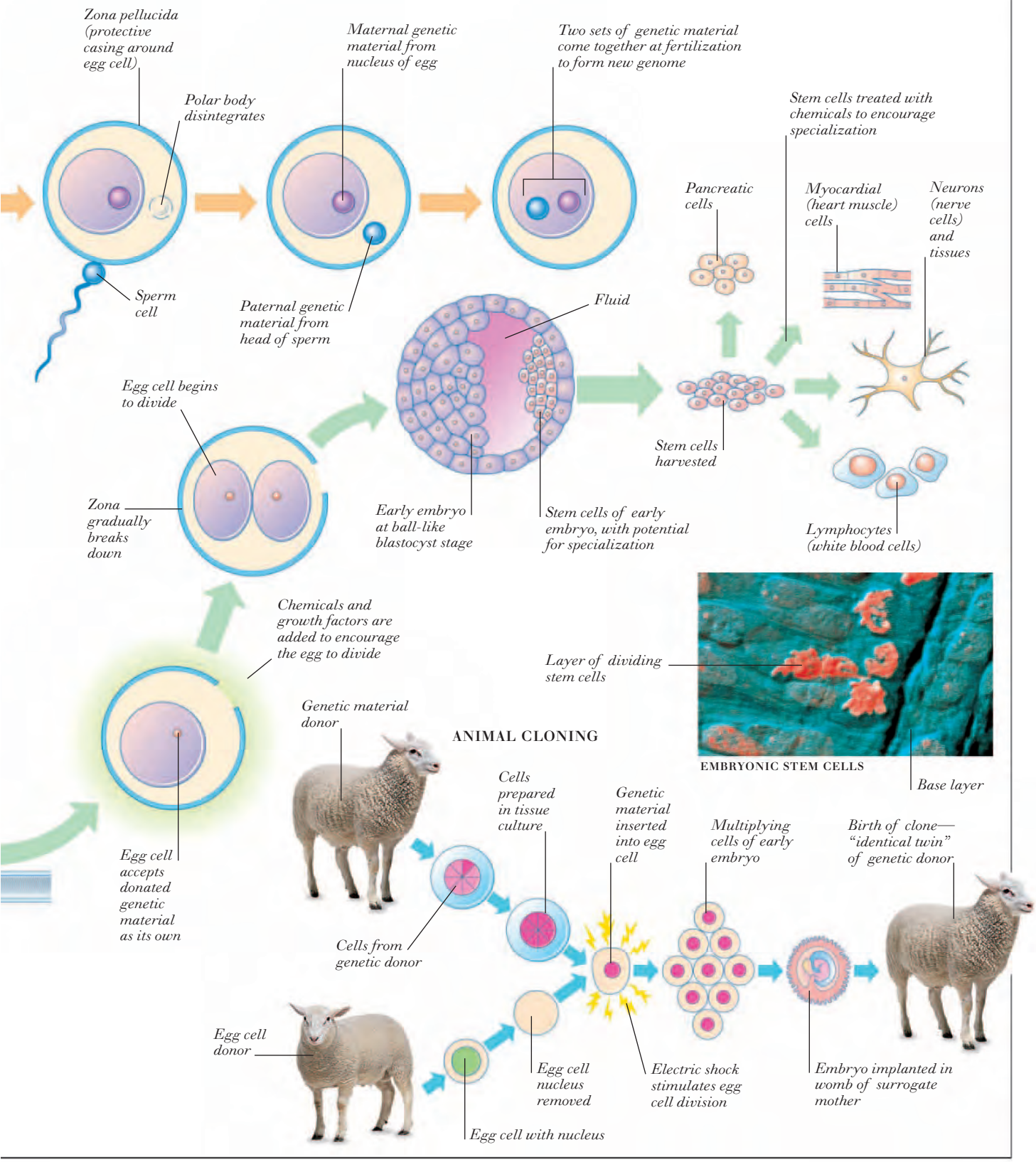
GEL IMAGE SHOWING DNA PROFILE





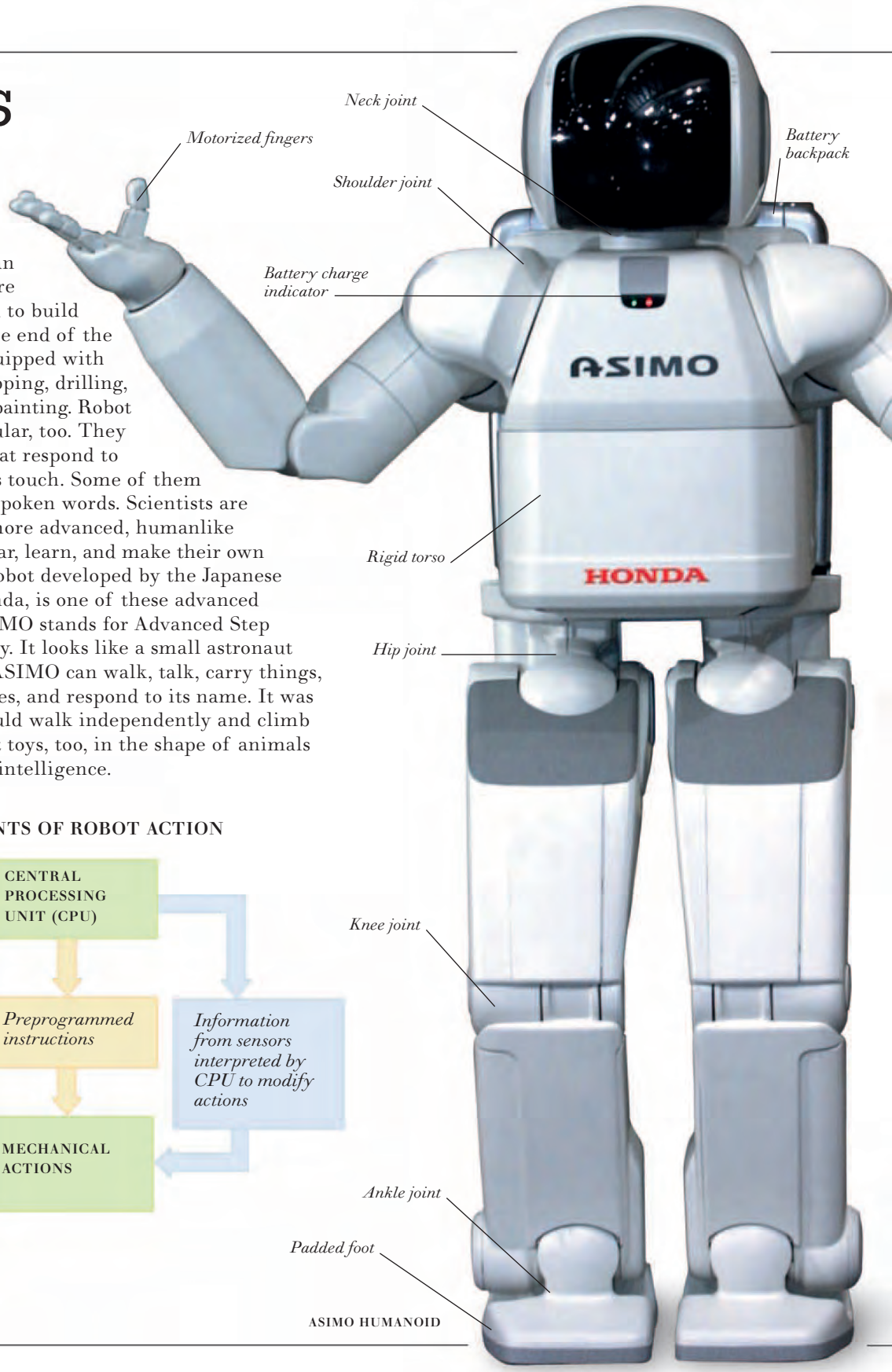
CENETIC MATERIAL REMOVED FROM EGG




Zona pellucida (protective casing around egg cell)
Polar body disintegrates
Maternal genetic material from nucleus of egg
Two sets of genetic material come together at fertilization to form new genome
Stem cells treated with chemicals to encourage specialization
Pancreatic cells
Myocardial (heart muscle) cells
Neurons (nerve cells) and tissues
Sperm cell
Paternal genetic material from head of sperm
Fluid
Egg cell begins to divide
Zona gradually breaks down
Early embryo at ball-like blastocyst stage
Stem cells of early embryo, with potential for specialization
Stem cells harvested
Lymphocytes (white blood cells)
Chemicals and growth factors are added to encourage the egg to divide
Layer of dividing stem cells
EMBRYONIC STEM CELLS
Base layer
ANIMAL CLONING
Genetic material donor
Egg cell accepts donated genetic material as its own
Cells prepared in tissue culture
Cells from genetic donor
Genetic material inserted into egg cell
Multiplying cells of early embryo
Birth of clone—"identical twin" of genetic donor
Egg cell donor
Egg cell nucleus removed
Egg cell with nucleus
Electric shock stimulates egg cell division
Embryo implanted in womb of surrogate mother

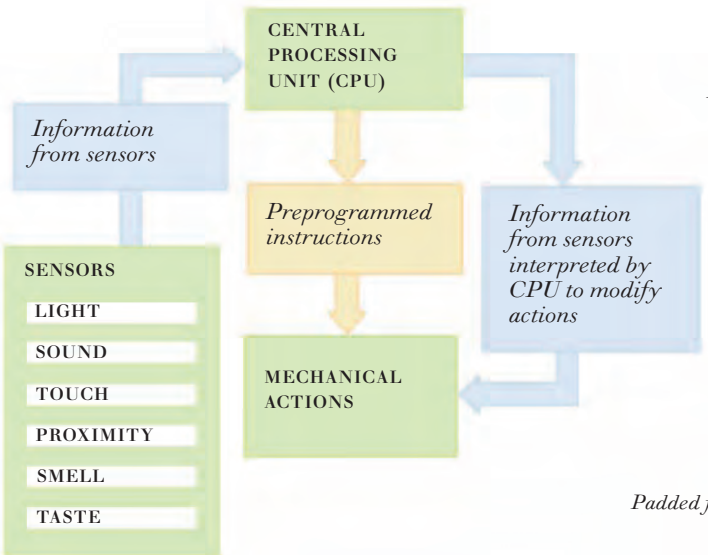
Robots

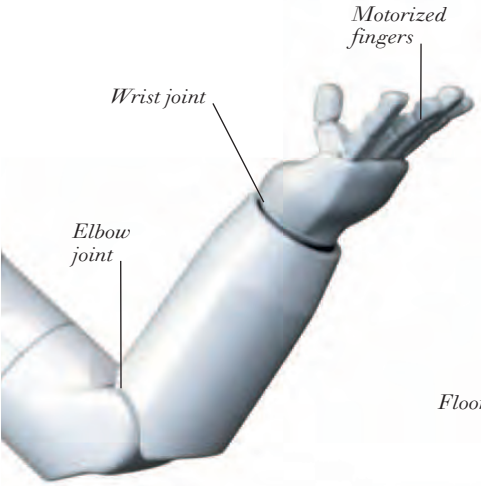
ROBOTS ARE MACHINES THAT CAN carry out a variety of tasks on their own, with little or no human control. Most robots are mechanical arms used to build things in factories. The end of the robot's arm can be equipped with different tools for gripping, drilling, cutting, welding, and painting. Robot toys have become popular, too. They incorporate sensors that respond to sounds and sometimes touch. Some of them can even understand spoken words. Scientists are also trying to create more advanced, humanlike robots that can see, hear, learn, and make their own decisions. ASIMO, a robot developed by the Japanese car manufacturer Honda, is one of these advanced humanoid robots. ASIMO stands for Advanced Step in Innovative MObility. It looks like a small astronaut wearing a backpack. ASIMO can walk, talk, carry things, recognize familiar faces, and respond to its name. It was the first robot that could walk independently and climb stairs. There are robot toys, too, in the shape of animals with simple artificial intelligence.

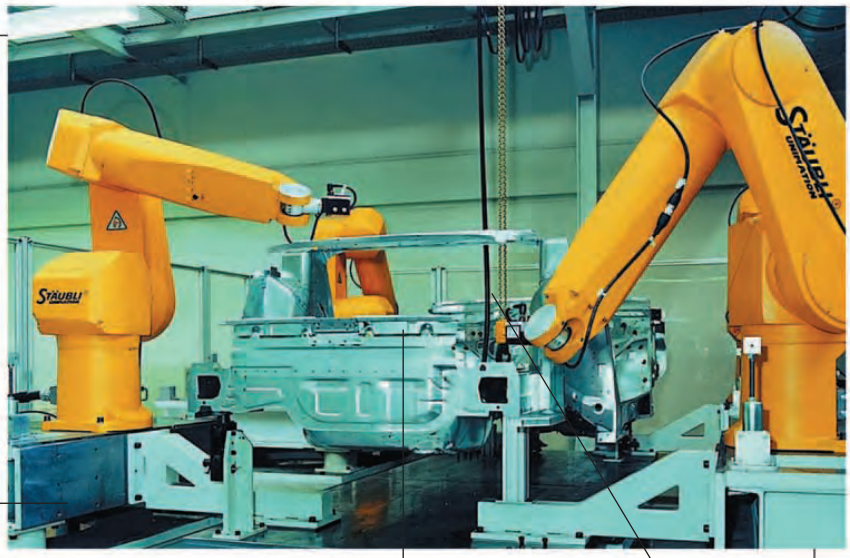


ASIMO HUMANOID

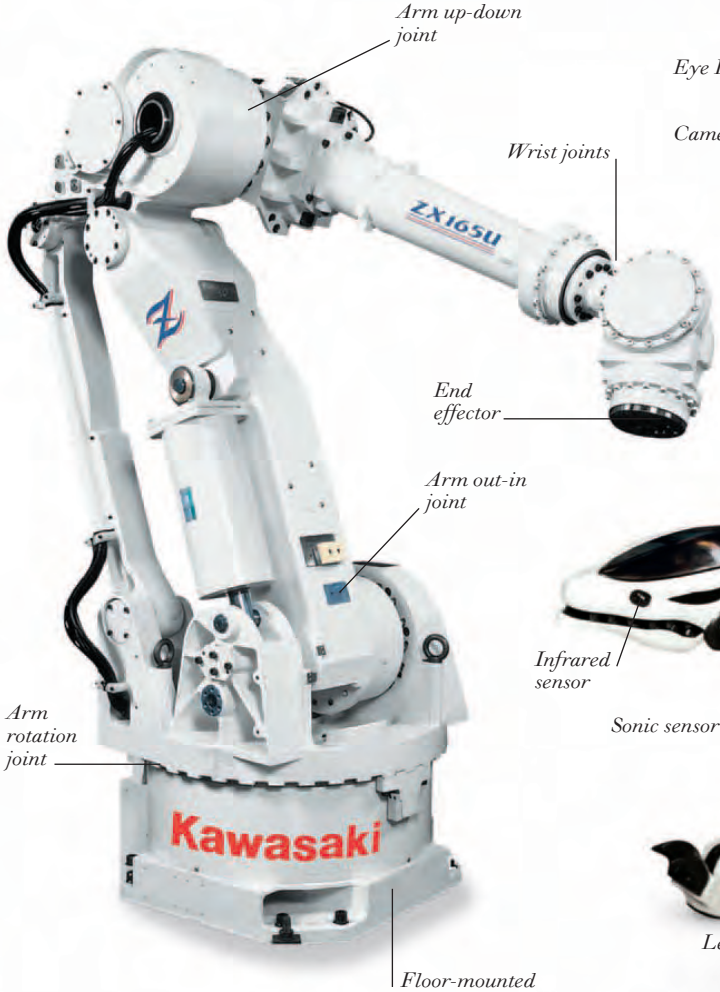
ELEMENTS OF ROBOT ACTION



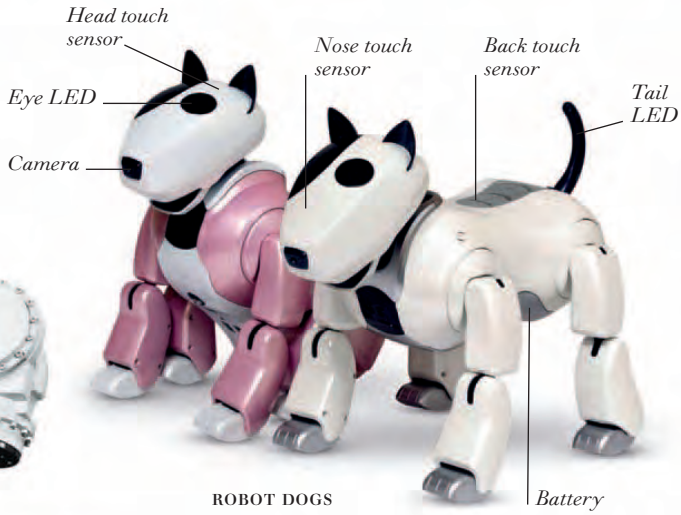




CAR-BUILDING ROBOTS



KAWASAKI INDUSRIAL ROBOT



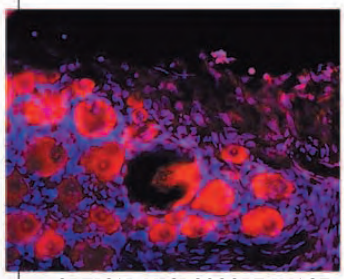
ROBOT DOGS

ROBOREPTILE

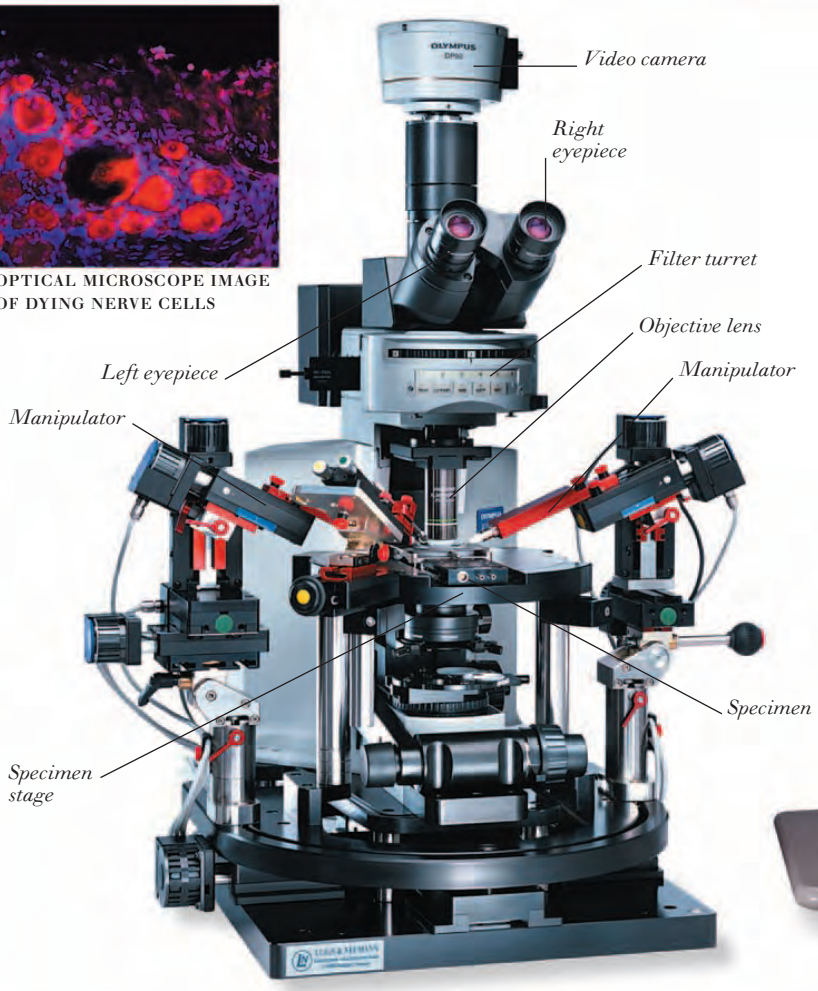
High-performance microscopes

OPTICAL MICROSCOPES FORM A MAGNIFIED image by using lenses to bend light. Some special-purpose optical microscopes used in industry and research are designed for observing particular materials, such as living cells. They produce magnifications of up to about 2,000. Electron microscopes produce magnifications of as much as 50 million, although 2 million is more typical. Their images are formed by means of electrons focused by magnetic lenses. There are two main types: scanning electron microscopes (SEMs) scan electrons back and forth across the surface of a specimen; transmission electron microscopes (TEMs) transmit electrons through a thin slice of the specimen.

TEM IMAGE OF A VIRUS

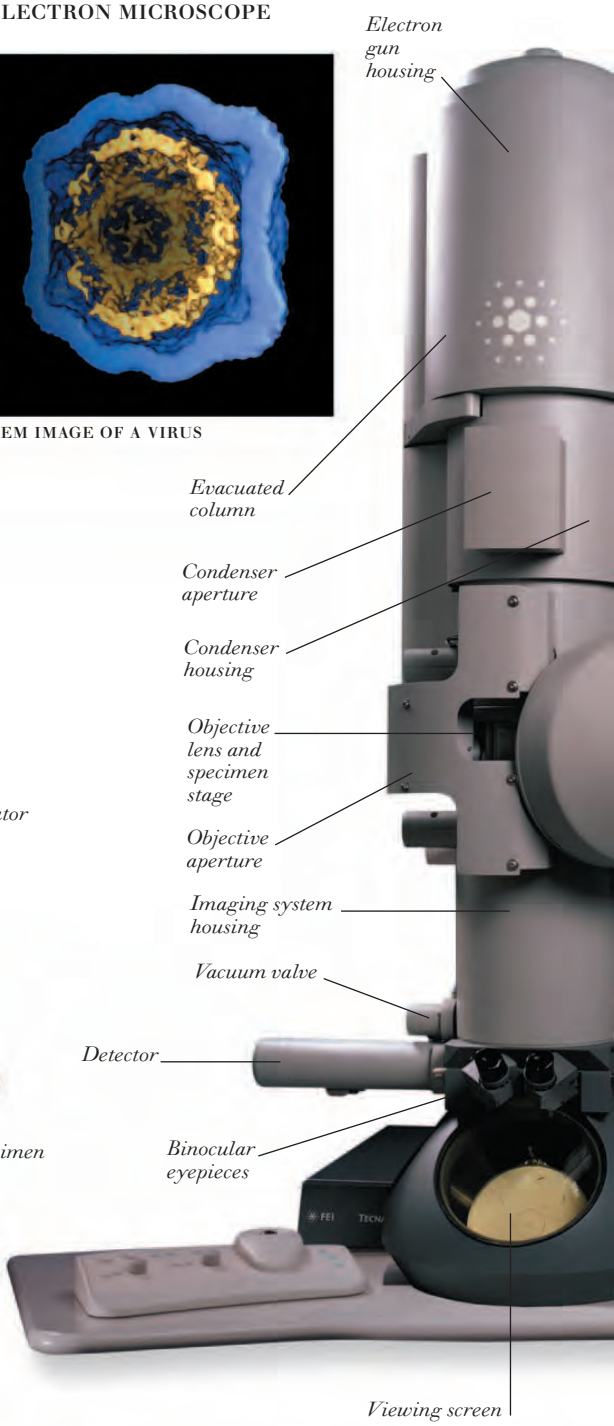


OPTICAL MICROSCOPE IMAGE OF DYING NERVE CELLS

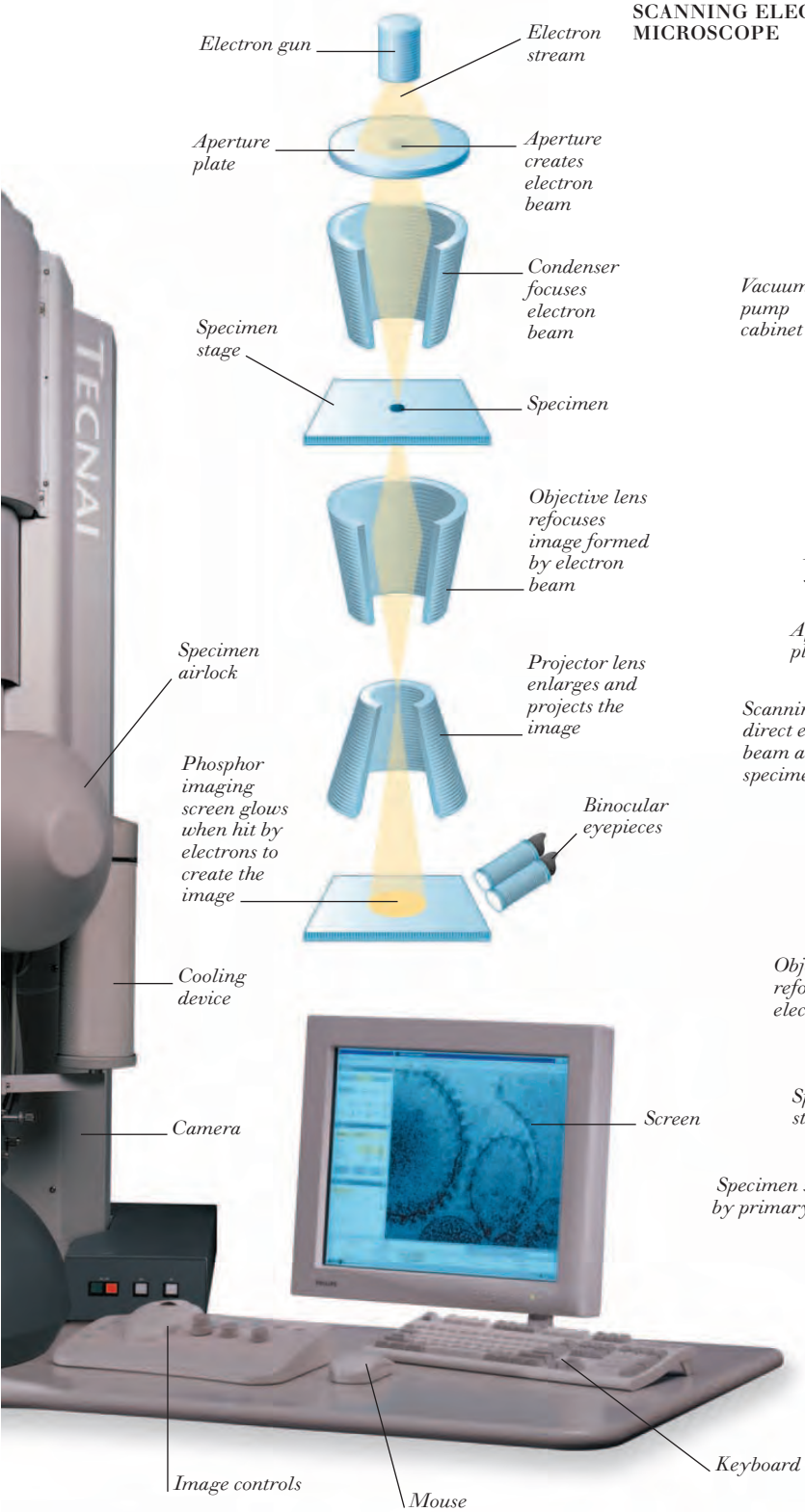


OLYMPUS BX51W1 OPTICAL MICROSCOPE

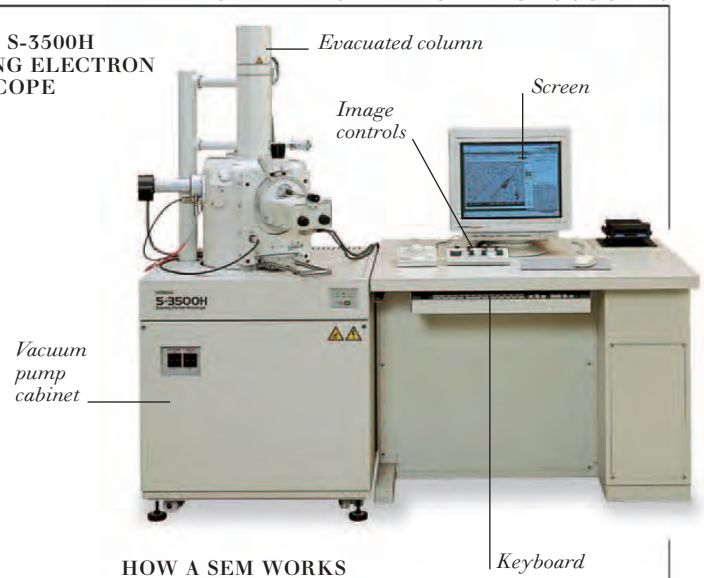
FEI TECNAI G² TRANSMISSION ELECTRON MICROSCOPE



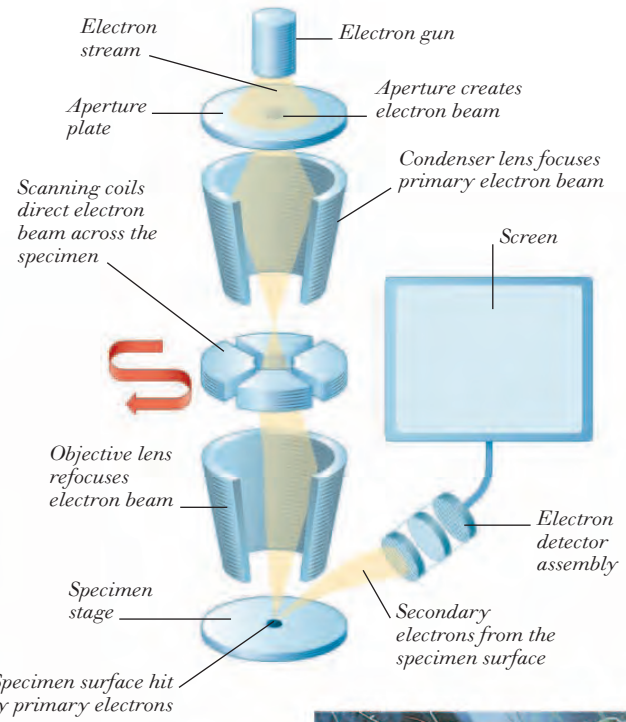
HOW A TEM WORKS

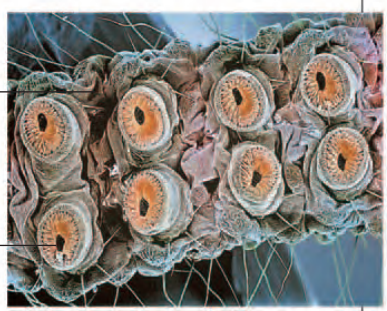


HITACHI S-3500H SCANNING ELECTRON MICROSCOPE



HOW A SEM WORKS





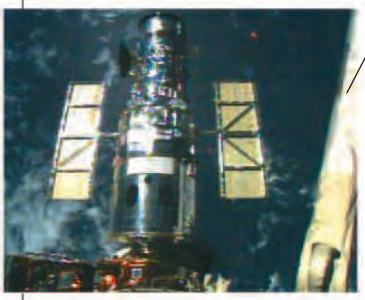
SEM IMAGE OF A CATERPILLAR

Space telescope

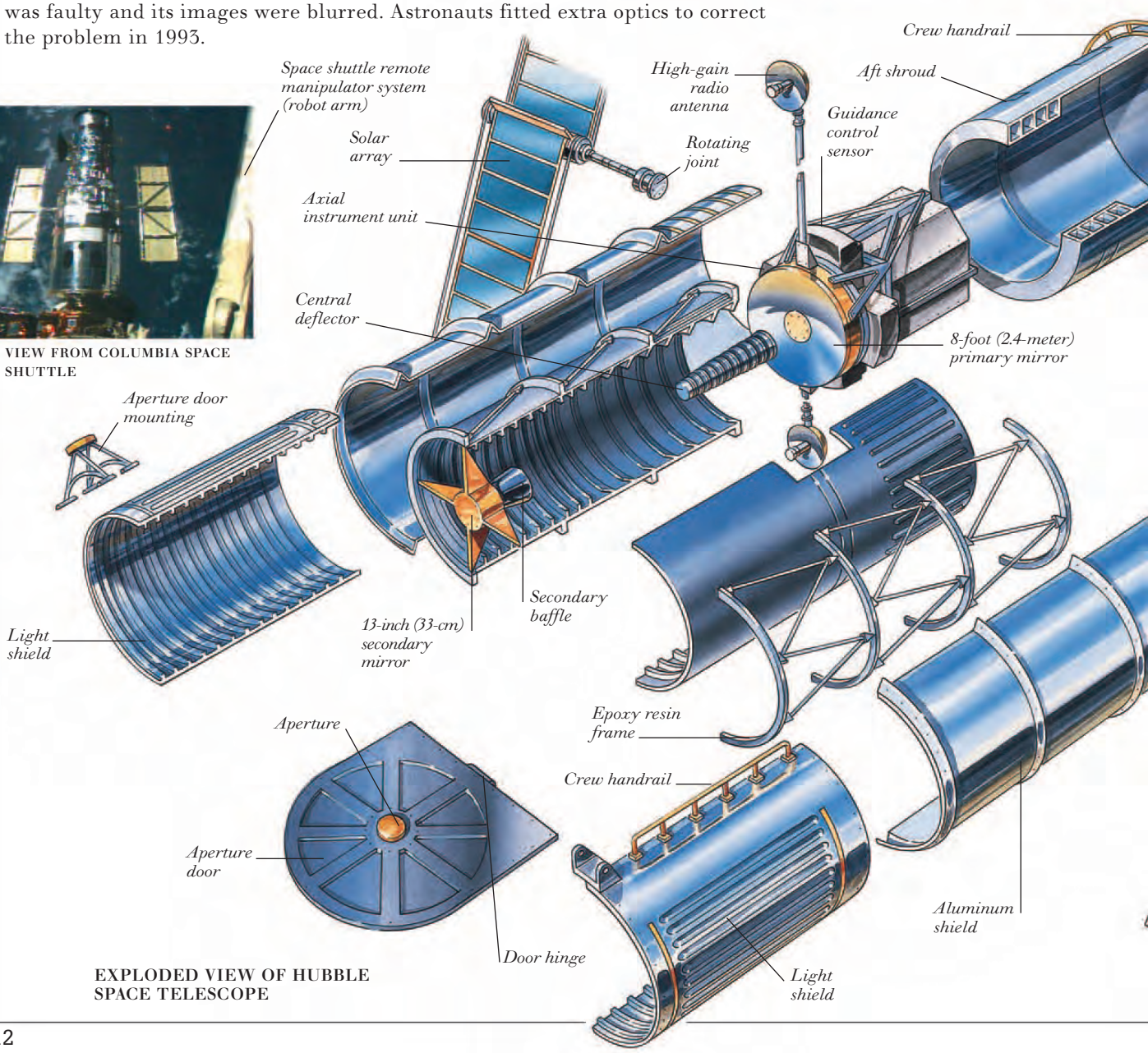
SPACE TELESCOPES ORBIT THE EARTH hundreds of miles above the ground, their instruments collecting light from stars and galaxies. Telescopes in space have a clearer view than those on Earth, because they are unaffected by the Earth's atmosphere, which absorbs or distorts much of this radiation. There are a variety of types of space telescope designed to observe different types of light. The Hubble Space Telescope observes infrared, ultraviolet, and visible light. It can detect objects that are 100 times fainter than those any telescopes on Earth can see. When this 12-ton (11,000-kilogram), 43-foot (13-meter) long telescope was launched by the Space Shuttle in 1990, it was found that its primary mirror was faulty and its images were blurred. Astronauts fitted extra optics to correct the problem in 1993.

IMAGES TAKEN BY HUBBLE

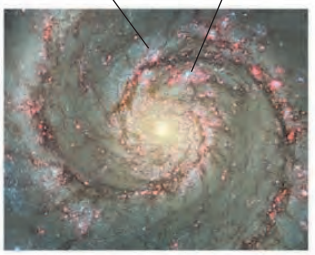
CONE NEBULA



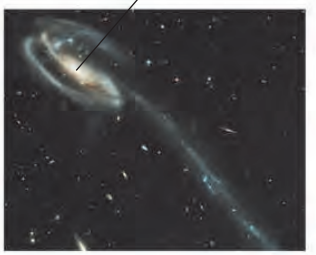
VIEW FROM COLUMBIA SPACE SHUTTLE



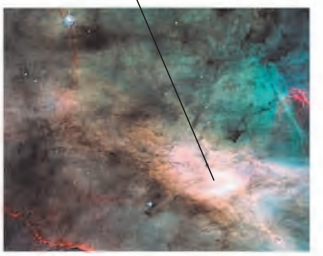
EXPLODED VIEW OF HUBBLE SPACE TELESCOPE



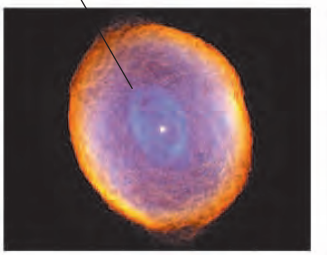
"WHIRLPOOL" GALAXY



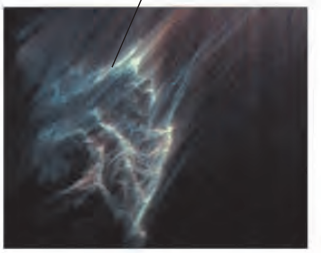
DRACO CONSTELLATION



OMEGA NEBULA

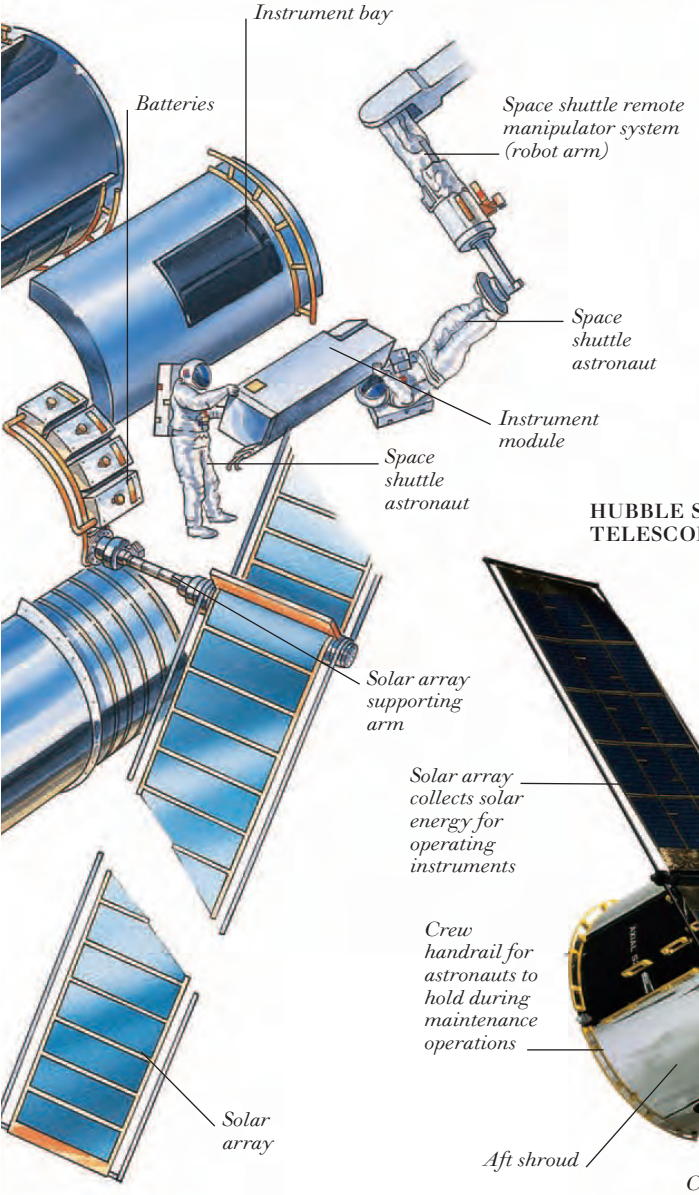


LEPUS CONSTELLATION

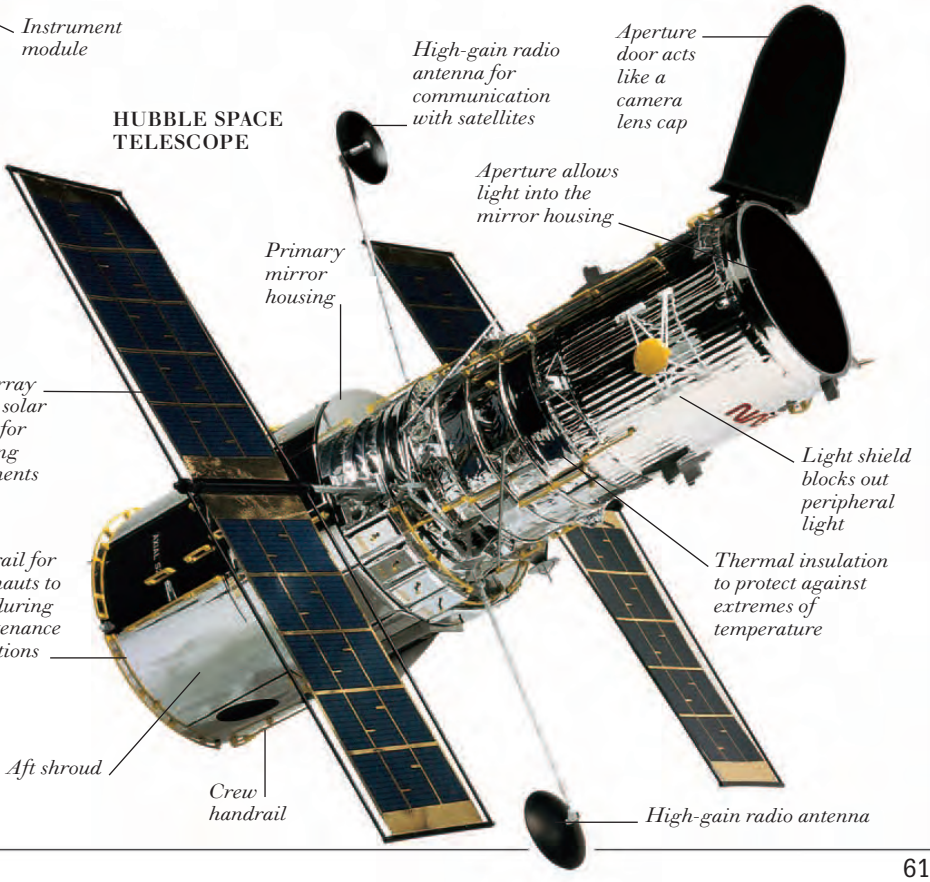


PLEIADES STAR CLUSTER

GREAT NEBULA, ORION

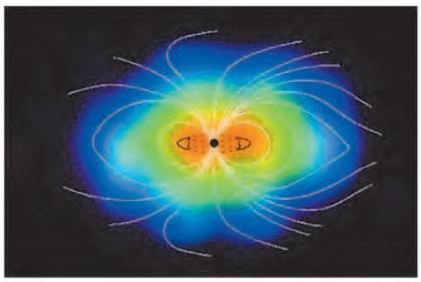


HUBBLE SPACE TELESCOPE

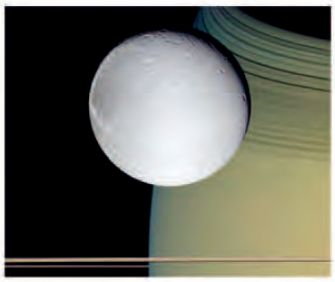


Probing the solar system

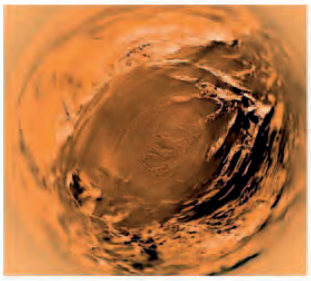
SPACE PROBES HAVE VISITED every planet in the solar system. They take photographs and gather data that cannot be collected using Earth-based equipment. Some probes fly past or orbit around planets or moons, while others land. Two Voyager space probes flew past the outer planets in the 1970s and 1980s. Two Viking spacecraft landed on Mars in 1976. The Magellan spacecraft orbited Venus from 1989 and mapped its surface. The Pathfinder spacecraft landed on Mars in 1997 and released a rover vehicle to explore the surface. The Mars Exploration Rover (MER) Mission landed two rovers in 2003. The Cassini space probe reached Saturn in 2004, and in 2005 its mini-probe, Huygens, landed on one of its moons, Titan, and became the first probe to land on a moon of another planet.



A MAP OF JUPITER'S VAST MAGNETIC FIELD PRODUCED BY CASSINI'S INSTRUMENTS

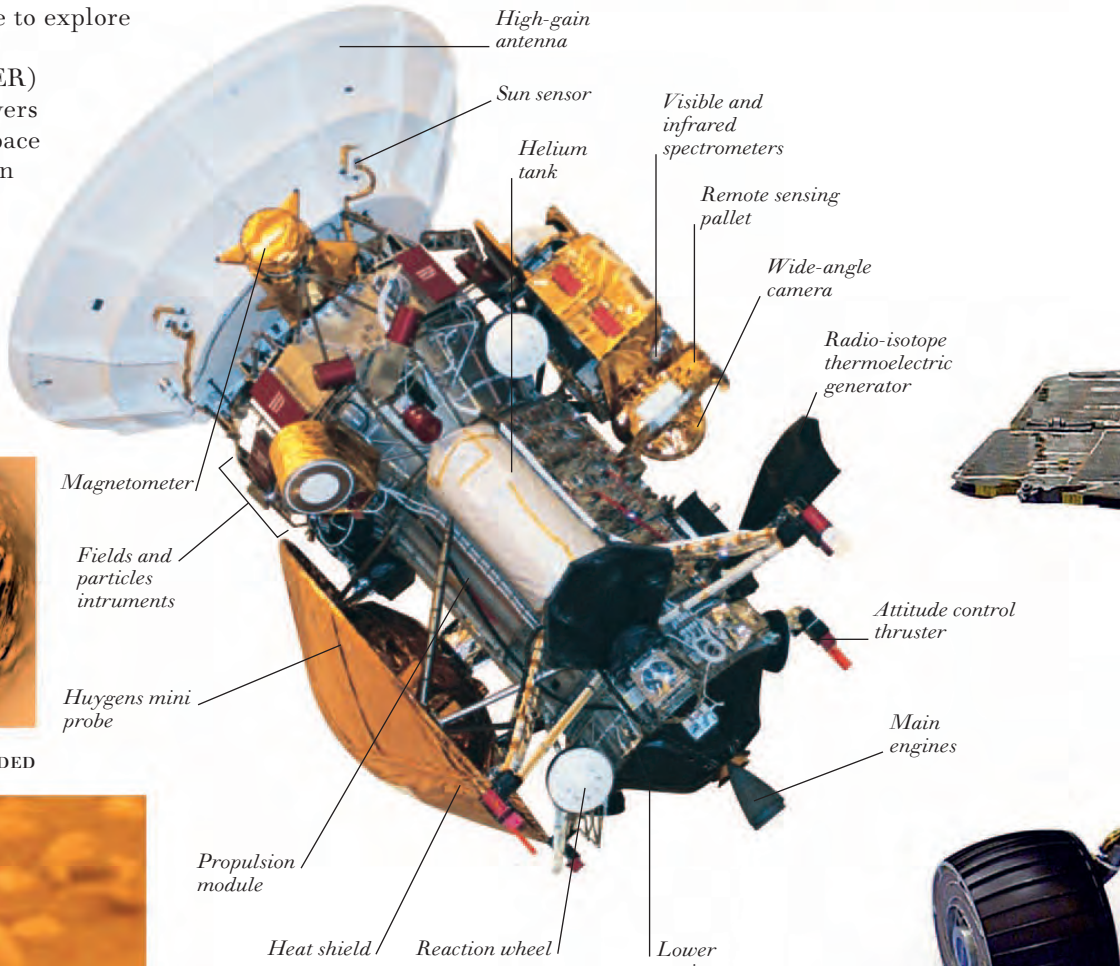


DIONE, ONE OF SATURN'S MOONS, ORBITING ABOVE THE "A" RING

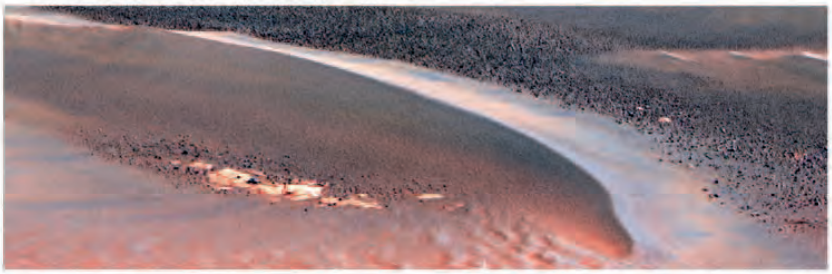


PANORAMIC VIEW OF TITAN TAKEN AS HUYGENS DESCENDED

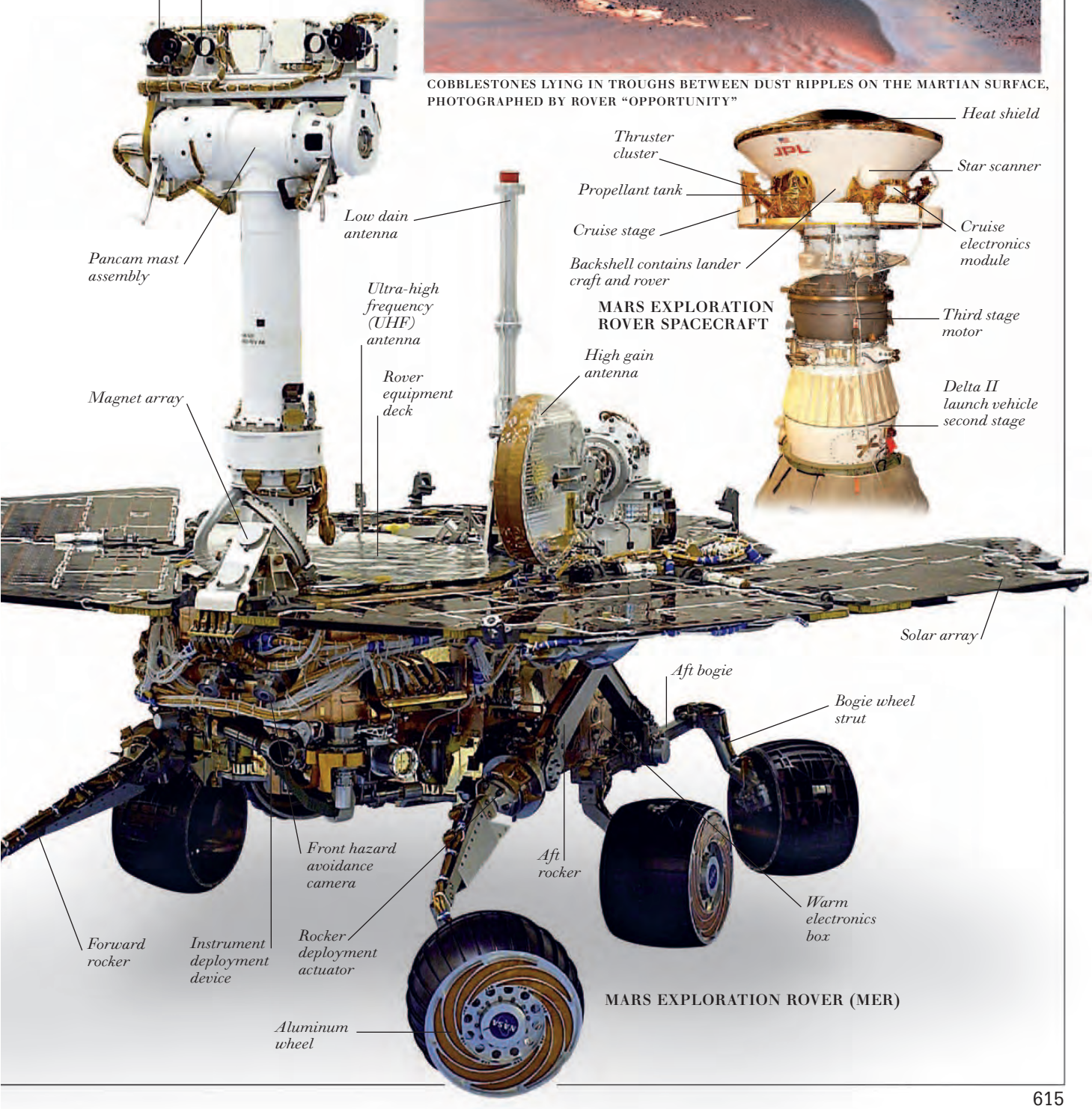
THE ROCK-STREWN SURFACE OF TITAN, PHOTOGRAPHED BY HUYGENS



CASSINI SPACE PROBE AND HUYGENS MINI-PROBE



COBBLESTONES LYING IN TROUGHS BETWEEN DUST RIPPLES ON THE MARTIAN SURFACE, PHOTOGRAPHED BY ROVER "OPPORTUNITY"



Political map of the world

This map depicts the political boundaries of the world's nations. There are currently 196 independent countries in the world—a marked increase from the 82 that existed in 1950. With the trend toward greater fragmentation, most recently with the creation of Southern Sudan in July 2011, this figure is likely to increase. The largest country in the world is the Russian Federation, which covers 6,592,800 square miles (17,075,400 sq km), while the smallest is the Vatican City, covering 0.17 square miles (0.44 sq km). Under the Antarctic Treaty of 1959, no countries are permitted territorial claims in Antarctica.

ABBREVIATIONS

AFGH.	Afghanistan
ALB.	Albania
AUT.	Austria
AZ. OR AZERB.	Azerbaijan
B. & H.	Bosnia & Herzegovina
BELG.	Belgium
BELO.	Belorussia
BOTS.	Botswana
BULG.	Bulgaria
CAMB.	Cambodia
C.A.R.	Central African Republic
CRO.	Croatia
CZ. REP.	Czech Republic
DOM. REP.	Dominican Republic
EST.	Estonia
HUNG.	Hungary
KYRG.	Kyrgyzstan
LAT.	Latvia
LIECH.	Liechtenstein
LITH.	Lithuania
LUX.	Luxemburg
MACED.	Macedonia
MOLD.	Moldavia
MON.	Montenegro
NETH.	Netherlands
PORT.	Portugal
ROM.	Romania
RUSS. FED.	Russian Federation
SLVK.	Slovakia
SLVN.	Slovenia
S.M.	San Marino
SWITZ.	Switzerland
TAJ.	Tajikistan
THAI.	Thailand
TURKMEN.	Turkmenistan
U.A.E.	United Arab Emirates
UZBEK.	Uzbekistan
VAT. CITY	Vatican City
ZIMB.	Zimbabwe

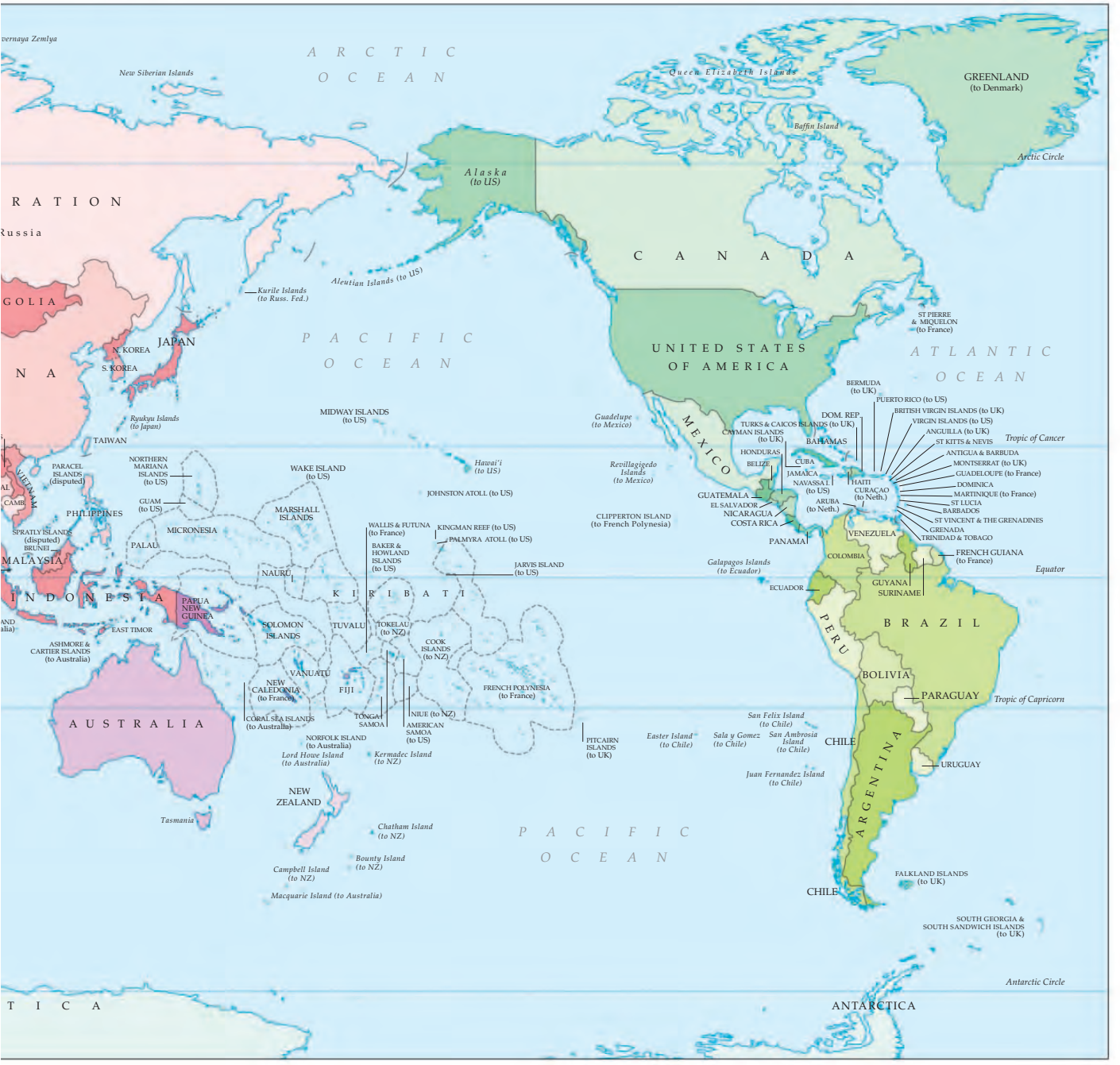
KEY

CONTINENTS

- Europe
- Africa
- Asia
- Australasia & Oceania
- North & Central America
- South America
- Antarctica

LABEL STYLES

E.g., MEXICO	Independent state
E.g., FAEROE ISLANDS (*to Denmark*)	Self-governing territory (parent state)
E.g., *Andaman Islands* (*to India*)	Non self-governing territory (parent state)



Time zones

The world is divided into 24 time zones, measured in relation to 12 noon Coordinated Universal Time (UTC), on the Greenwich Meridian (0°). Time advances by one hour for every 15° longitude east of Greenwich (and goes back one hour for every 15° west), but the system is adjusted in line with administrative boundaries. Numbers on the map indicate the number of hours that must be added to, or subtracted from UTC to calculate the time in each zone. Thus, the eastern United States (–5) is 5 hours behind UTC.

TYPES OF CALENDAR

GREGORIAN

The 365-day Gregorian calendar was introduced by Pope Gregory XIII in 1582 and is now in use throughout most of the Western world. Every four years (leap year) an extra day is added. Below are the names of the months (and number of days).

January (31)
February (28, 29 in leap years)
March (31)
April (30)
May (31)
June (30)
July (31)
August (31)
September (30)
October (31)
November
December (31)

JEWISH

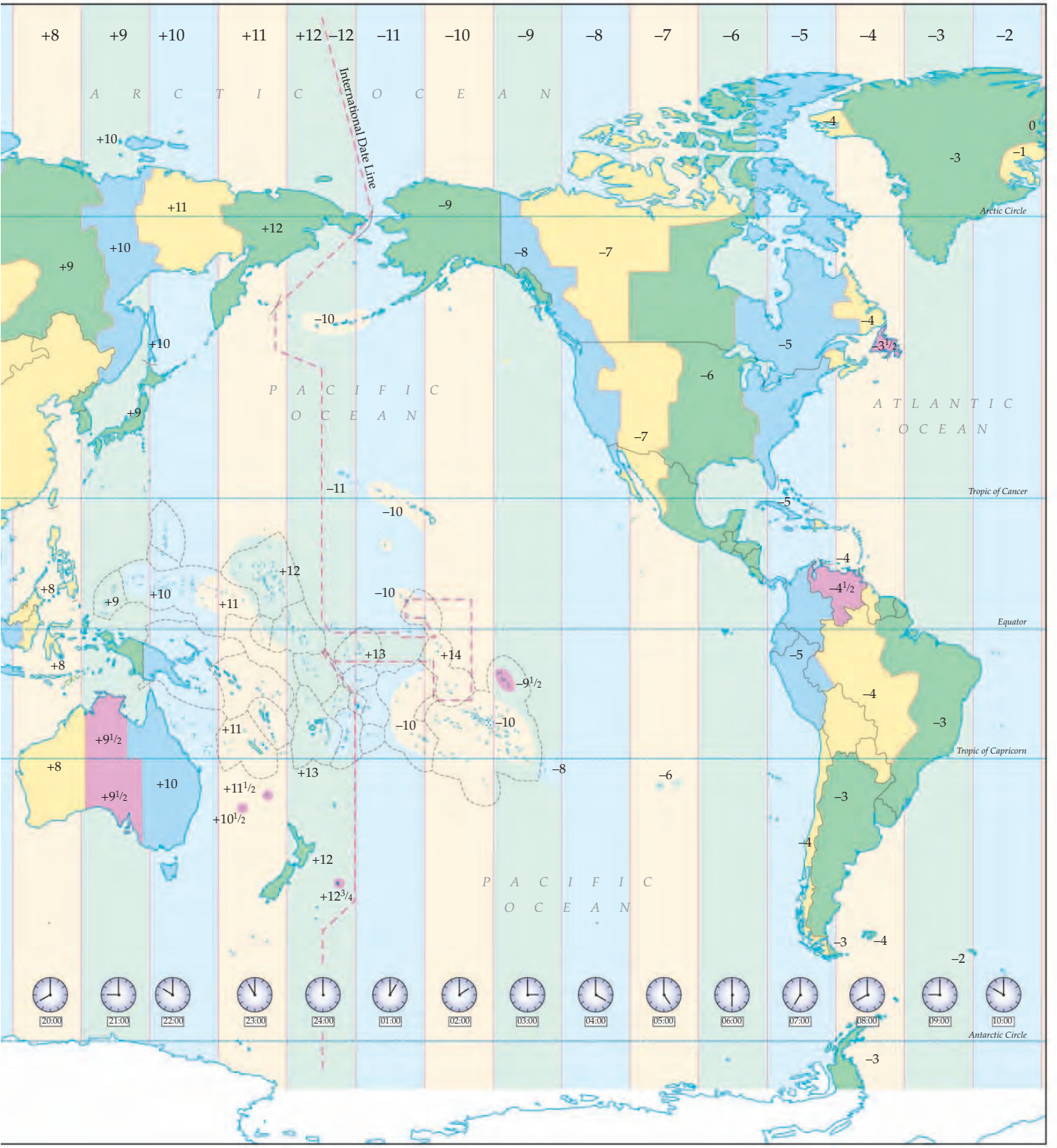
The Jewish calendar is a lunar calendar adapted to the solar year. It normally has 12 months but in leap years, which occur seven times in every cycle of 19 years, there are 13 months. The years are calculated from the Creation (which is placed at 3761 BC); the months are Nisan, Iyyar, Sivan, Thammuz, Ab, Elul, Tishri, Hesvan, Kislev, Tebet, Sebat, and Adar, with an intercalary month (First Adar) being added in leap years.

MUSLIM

The Muslim calendar is based on a year of 12 months, each month beginning roughly at the time of the New Moon. The months are Muharram, Safar, Rabi'I, Rabi'II, Jumada I, Jumada II, Rajab, Sha'ban, Ramadan, Shawwal, Dhu l-Qa'dah, and Dhu l-Hijja.

CHINESE

The Chinese calendar is a lunar calendar, with a year consisting of 12 months. Intercalary months are added to keep the calendar in step with the solar year of 365 days. Months are referred to by a number within a year, but also by animal names that, from ancient times, have been attached to years and hours of the day.


+8
+9
+10
+11
+12
–12
–11
–10
–9
–8
–7
–6
–5
–4
–3
–2
A R C T I C O C E A N
International Date Line
Arctic Circle
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic Circle
P A C I F I C O C E A N
A T L A N T I C O C E A N
+9½
+10½
+11½
+12¾
–4½
–3½
–9½
+13
+14
20:00
21:00
22:00
23:00
24:00
01:00
02:00
03:00
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05:00
06:00
07:00
08:00
09:00
10:00

Useful data

UNITS OF MEASUREMENT

METRIC UNIT	EQUIVALENT
Length	
1 centimeter (cm)	10 millimeters (mm)
1 meter (m)	100 centimeters
1 kilometer (km)	1,000 meters
Mass	
1 kilogram (kg)	1,000 grams (g)
1 metric ton (t)	1,000 kilograms
Area	
1 square centimeter (cm^2)	100 square millimeters (mm^2)
1 square meter (m^2)	10,000 square centimeters
1 hectare	10,000 square meters
1 square kilometer (km^2)	1,000,000 square meters
Volume	
1 cubic centimeter (cc)	1 milliliter (ml)
1 liter (l)	1,000 milliliters
1 cubic meter (m^3)	1,000 liters
Capacity (liquid and dry measures)	
1 centiliter (cl)	10 milliliters (ml)
1 deciliter (dl)	10 centiliters
1 liter (l)	10 deciliters
1 decaliter (dal)	10 liters
1 hectoliter (hi)	10 decaliters
1 kiloliter (kl)	10 hectoliters

IMPERIAL UNIT	EQUIVALENT
Length	
1 foot (ft)	12 inches (in)
1 yard (yd)	3 feet
1 rod (rd)	5½ yards
1 mile (mi)	1,760 yards
Mass	
1 dram (dr)	27.344 grains (gr)
1 ounce (oz)	16 drams
1 pound (lb)	16 ounces
1 hundredweight (cwt) (long)	112 pounds
1 hundredweight (cwt) (short)	100 pounds
1 ton (long)	2,240 pounds
1 ton (short)	2,000 pounds
Area	
1 square foot (ft^2) (in^2)	144 square inches
9 square feet	1 square yard (yd^2)
1 acre	4,840 square yards
1 square mile	640 acres
Volume	
1 cubic foot	1,728 cubic inches
1 cubic yard	27 cubic feet
Capacity (liquid and dry measures)	
1 fluidram (fl dr)	60 minims (min)
1 fluid ounce (fl oz)	8 fluidrams
1 gill (gi)	5 fluid ounces
1 pint (pt)	4 gills
1 quart (qt)	2 pints
1 gallon (gal)	4 quarts
1 peck (pk)	2 gallons
1 bushel (bu)	4 pecks

NUMBER SYSTEMS

ROMAN	ARABIC
I	1
II	2
III	3
IV	4
V	5
VI	6
VII	7
VIII	8
IX	9
X	10
XI	11
XII	12
XIII	13
XIV	14
XV	15
XX	20
XXI	21
XXX	30
XL	40
L	50
LX	60
LXX	70
LXXX	80
XC	90
C	100
CI	101
CC	200
CCC	300
CD	400
D	500
DC	600
DCC	700
DCCC	800
CM	900
M	1,000
MM	2,000

METRIC TO IMPERIAL CONVERSIONS

TO CONVERT	INTO	MULTIPLY BY
Length		
Centimeters	inches	0.3937
Meters	feet	3.2810
Kilometers	miles	0.6214
Meters	yards	1.0940
Mass		
Grams	ounces	0.0352
Kilograms	pounds	2.2050
Metric tons	long tons	0.9843
Metric tons	short tons	1.1025
Area		
Square centimeters	square inches	0.1550
Square meters	square feet	10.7600
Hectares	acres	2.4710
Square kilometers	square miles	0.3861
Square meters	square yards	1.1960
Volume		
Cubic centimeters	cubic inches	0.0610
Cubic meters	cubic feet	35.3100
Capacity		
Liters	pints	1.7600
Liters	gallons	0.2200

IMPERIAL TO METRIC CONVERSIONS

TO CONVERT	INTO	MULTIPLY BY
Length		
Inches	centimeters	2.5400
Feet	meters	0.3048
Miles	kilometers	1.6090
Yards	meters	0.9144
Mass		
Ounces	grams	28.3500
Pounds	kilograms	0.4536
Long tons	metric tons	1.0160
Short tons	metric tons	0.9070
Area		
Square inches	square centimeters	6.4520
Square feet	square meters	0.0929
Acres	hectares	0.4047
Square miles	square kilometers	2.5900
Square yards	square meters	0.8361
Volume		
Cubic inches	cubic centimeters	16.3900
Cubic feet	cubic meters	0.0283
Capacity		
Pints	liters	0.5683
Gallons	liters	4.5460

RULES OF ALGEBRA

EXPRESSION	COMMENTS	EXPRESSION BECOMES
a + a	Simple addition	2a
a + b = c + d	Subtract *b* from either side	a = c + d - b
ab = cd	Divide both sides by b	a = cd ÷ b
(a + b) (c + d)	Multiplication of bracketed terms	ac + ad + be + bd
a^2 + ab	Use parentheses	a(a + b)
$(a + b)^2$	Expand terms in parentheses	$a^2 + 2ab + b^2$
a^2—b^2	Difference of two squares	(a + b)(a-b)
1/a + 1/b	Find common denominator	(a + b)/ab
a/b ÷ c/d	Dividing by a fraction is the same as multiplying by its reciprocal	a/b × d/c

POWERS OF TEN USED WITH SCIENTIFIC UNITS

FACTOR	NAME	PREFIX	SYMBOL
10^{18}	quintillion	exa-	E
10^{15}	quadrillion	peta-	P
10^{12}	trillion	tera-	T
10^{9}	billion	giga-	G
10^{6}	million	mega-	M
10^{3}	thousand	kilo-	k
10^{2}	hundred	hecto-	h
10^{1}	ten	deca-	da
10^{-1}	one-tenth	deci-	d
10^{-2}	one-hundredth	centi-	c
10^{-3}	one-thousandth	milli-	m
10^{-6}	one-millionth	micro-	u
10^{-9}	one-billionth	nano-	n
10^{-12}	one-trillionth	pico-	p
10^{-15}	one-quadrillionth	femto-	f
10^{-18}	one-quintillionth	atto-	a

Note: The American system of numeration for denominations above one million is used in this book. In this system, each of the denominations above one billion (1,000 millions) is 1,000 times the preceding one.

BIOLOGY SYMBOLS

SYMBOL	MEANING
o	female individual (used in inheritance charts)
□	male individual (used in inheritance charts)
♀	female
♂	male
×	crossed with; hybrid
+	wild type
F_1	offspring of the first generation
F_2	offspring of the second generation

TEMPERATURE SCALES

To convert from Fahrenheit (F) to Celsius (C): C = (F—32) × 5 ÷ 9
To convert from Celsius to Fahrenheit: F = (C × 9 ÷ 5) + 32
To convert from Celsius to Kelvin (K): K = C + 273
To convert from Kelvin to Celsius: C = K - 273

Celsius	-20	-10	0	10	20	30	40	50	60	70	80	90	100
Fahrenheit	-4	14	32	50	68	86	104	122	140	158	176	194	212
Kelvin	253	263	273	283	293	305	313	325	333	343	353	363	373

PHYSICS SYMBOLS

SYMBOL	MEANING
α	alpha particle
β	beta ray
γ	gamma ray; photon
ε	electromotive force
η	efficiency; viscosity
λ	wavelength
μ	micro-; permeability
ν	frequency; neutrino
ρ	density; resistivity
σ	conductivity
c	velocity of light
e	electronic charge

MATHEMATICAL SYMBOLS

SYMBOL	EXPLANATION
+	addition
-	subtraction
×	multiplication
÷	division
=	equals
≠	does not equal
>	greater than
<	less than
≥	greater than or equal to
≤	less than or equal to
∞	infinity
%	percent
π	pi (3.1416)
°	degree
≈	is approximately equal to
∠	angle
∥	parallel to
∑	summation
u, u	vectors
f(x)	function
!	factorial
√	square root
ξ	universal set
A ∩ B	intersection
A ∪ B	unison
A ⊂ B	subset
Ø	null set

CHEMISTRY SYMBOLS

SYMBOL	MEANING
+	plus; together with
–	single bond
•	single bond; single unpaired electron; two separate parts or compounds regarded as loosely joined
=	double bond
≡	triple bond
R	group
X	halogen atom
Z	atomic number

SCIENTIFIC NOTATION

NUMBER	NUMBER BETWEEN 1 AND 10	POWER OF TEN	SCIENTIFIC NOTATION
10	1	10^1	1 3 10^1
150	1.5	10^2 (= 100)	1.5 3 10^2
274,000,000	2.74	10^8 (= 100,000,000)	2.74 3 10^8
0.0023	2.3	10^{-3} (= 0.001)	2.3 3 10^{-3}

TRIGONOMETRY

Angle A (degrees)	sin A	cos A	tan A
0	0	1	0
30	1/2	√3/2	1/√3
45	1/√2	1/√2	1
60	√3/2	1/2	√ 3
90	1	0	∞

Shapes: Plane

Two-dimensional shapes are termed plane (or flat) shapes. Plane shapes constructed with straight sides, as illustrated here, are called polygons. They are categorized according to the number of sides they have—for example, three-sided polygons are known as triangles. A polygon that has sides of equal length and internal angles of equal size, such as a square, is said to be regular.

SCALENE TRIANGLE
A triangle (three-sided polygon) with no equal sides or angles.

ISOSCELES TRIANGLE
A triangle with only two sides and two angles equal.

RIGHT-ANGLED TRIANGLE
A triangle with one angle as a right angle (90°).

EQUILATERAL TRIANGLE
A regular triangle. All angles are 60°.

SQUARE
A regular quadrilateral. All angles are 90°.

RHOMBUS
A quadrilateral with all sides equal and two pairs of equal angles.

RECTANGLE
A quadrilateral with four right angles and opposite sides of equal length.

PARALLELOGRAM
A quadrilateral with two pairs of parallel sides.

TRAPEZIUM
A quadrilateral with one pair of parallel sides.

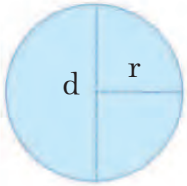
PENTAGON
A five-sided polygon. A regular pentagon is shown above.

HEXAGON
A six-sided polygon. A regular hexagon is shown above.

OCTAGON
An eight-sided polygon. A regular octagon is shown above.

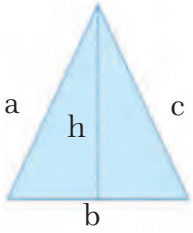
AREAS AND PERIMETERS

The formulae for calculating the areas and perimeters of simple plane shapes were devised by Classical Greek mathematicians.



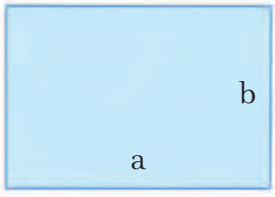
CIRCLE
r = radius
d = diameter = 2 × r

Circumference = 2 × π × r
Area = π × r^2
(π = 3.1416)



TRIANGLE
Height = h
Sides = a, b, c

Perimeter = a + b + c
Area = ½ × b × h



RECTANGLE
Sides = a, b

Perimeter = 2 × (a + b)
Area = a × b

Shapes: Solid

Three-dimensional shapes are known as solid shapes and include spheres, cubes, and pyramids. A solid shape with a polygon at each face is called a polyhedron.

TETRAHEDRON
A four-sided polyhedron. A regular tetrahedron is shown.

CUBE
A regular hexahedron. All sides are equal and all angles are 90°.

OCTAHEDRON
A polyhedron with eight sides.

PRISM
A polyhedron of constant cross-sections in planes perpendicular to its longitudinal axis.

PYRAMID
A polygonal base and triangular sides that meet at a point.

TORUS
A doughnutlike, ring shape.

SPHERE
A round shape, as in a ball or an orange.

HEMISPHERE
Formed when a sphere is cut exactly in half.

SPHEROID
An egg-shaped solid object whose cross-section is a circle or an ellipse.

CONE
An elliptical or circular base with sides tapering to a single point.

RIGHT CYLINDER
A tube-shaped, solid figure. A right cylinder has parallel faces.

HELIX
A twisted curve. The distance moved in one revolution is its pitch.

SURFACE AREAS AND VOLUMES

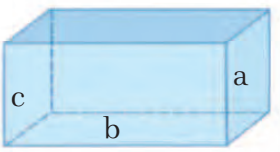
Volume refers to the amount of space that a solid object occupies. Its surface area is the sum of the area of each of its faces.

CYLINDER
Surface area =
$2 \times \pi \times r \times h + 2\pi r^2$
Volume = $\pi \times r^2 \times h$

Height = h
Radius = r

CONE
Surface area =
$\pi \times r \times l + \pi r^2$
Volume = $\frac{1}{3} \times \pi \times r^2 \times l$

Height = h
Radius = r
Side = l



RECTANGULAR BLOCK
Surface area =
2 (a × b + b × c + a × c)
Volume = a × b × c

Sides = a, b, c

Index

A

Aa lava 273
Abacus
  Ancient Egyptian temple 459
  Ancient Greek building 460
  Medieval church 469
  Neoclassical building 483
Abalone 176
Abaxial epidermis 139
Abaxial surface
  Butterwort leaf 161
  Fern pinnule 121
  Mulberry leaf 130
  Water hyacinth leaf 158
  Water lily leaf 159
  Welwitschia leaf 123
Abbey of St. Foi 468
Abdomen
  Crab 172
  Crayfish 172
  Human 211
  Insect 168-169
  Rattlesnake 185
  Scorpion 170
  Shrimp 172
  Spider 171
Abdominal aorta 215, 255
Abdominal artery 173
Abdominal cavity 215
Abdominal segment
  Butterfly 169
  Crayfish 172
  Eurypterid fossil 79
  Extinct shrimp 79
Abductor digiti minimus muscle 231, 233
Abductor pollicis brevis muscle 231
Aberdeen hook 562
Abies Concolor 66
Abomasum 198
Aboral surface
  Sea urchin 175
  Starfish 174
Abortive ovule 151
Abortive seed 146
Abrasion
  Glacier 286
  Weathering and erosion 282
Absolute magnitude
  Hertzsprung-Russell diagram 23
  Stars 22
Absorption lines 22-23
Absorptive hyphae 114
Abutment 484-485
Abyssal plain 298
Acacia tree sap 438
Acadagnostus 64
Acamar 19
Acanthostachys strobilacea 112-113
Acanthostega 80
Acanthus leaf 460
Accelerated electron 319
Acceleration 320-321
  Electric train 328
  Motorcycle 364
Access door 333
Accessory drive pad 419
Accessory pouch 548
Access panel 329, 333
Access slot 585
Accidentals 502-503
Accretion disc 27-29
AC electric train 328
Acer Lumiread e-reader 568
Acer pseudoplatanus 131, 151
Acer sp. 127
Acetabularia sp. 116
Acetabular labrum 225
Acetabulum
  Eryops 81
  Ornithischian 82
  Saurischian 82
Acetylene headlight 336-337
Achenes 150
Achernar 20
Achilles tendon 232-233
Acid
  Intaglio printing 446
  Reversible reaction 312
  Salt formation 312
Acidalia Planitia 43
Acidic solution 446, 448
Acid-resistant ground 446-447
Acid-secreting stomach cell 217
Acipenser sturio 180
Acorn 131
Acoustic guitar 512-513
Acropolis 460
Acrosomal cap 259
Acroterion 460-461
Acroteuthis 278
Acrux
  Centaurus and Crux 21
  Southern stars 21
Acrylic ink 448
Acrylic paint techniques 443
Acrylic-primed board 442
Acrylics 442-443
Actinia equina 166
Actinides 310
Actinium 310
Actinothoe sphyrodeta 166
Action 321
Action lever 514
Active galaxy 12
Active volcano 272
  Igneous and metamorphic rocks 275
  Mountain building 62
Actuating lever system 330
Acuminate leaf apex 136-137
Acute leaf apex 137
Adam's apple 212, 244-245
Adam's ring
  Neptune's rings 50
  Structure of Neptune 51
Adaptation 112
  Dryland plants 156-157
  Wetland plants 158-159
Adaxial epidermis 139
Adaxial surface
  Butterwort leaf 161
  Mulberry leaf 130
  Tree mallow leaf 131
  Water hyacinth leaf 158
  Water lily leaf 159
  Welwitschia leaf 123
Add address button 576
Add attachments button 576
Address options button 576
Adductor longus muscle 225, 226
Adductor magnus muscle 227
Adductor muscle 173
Adductor pollicis muscle 231
Adductor tubercle 225
Adenine 216
Adhara 18, 21
Adipose tissue 215, 235
Adjustable antenna 591
Adjustable damper 518
Adjustable link 362
Adjustable vane 563
Adjusting screw 560
Admiralty anchor Type ACII 386
Admiralty pattern anchor 386
Adrenal gland 215, 257
Adventitious buds 154
Adventitious roots
  Aechmea miniata 162
  Canadian pond weed 158
  Couch grass 113
  Fern 121
  Horsetail 120
  Ivy 131
  Monocotyledon 126
  Potato 128
  Rock stonecrop 128
  Tree fern 112
  Vegetative reproduction 154-155
  Water fern 158
  Water hyacinth 158
  Water lily 159
Advertising 368
Advertising panel 333
Aechmea miniata 162
Aedicule
  Ancient Roman building 463
  Renaissance building 474, 476
AEG Turbine Hall 495
Aegyptopithecus 75
Aeration zone 293
Aerial
  Frigate 397
  Honda Insight 354
  Renault Clio 349
Aerial mammals 104
Aerial rig 397
Aerial root 162
Aerial shoot 155
Aerial stem 119, 155
Aerodynamic balance 414-415
Aerodynamic hub cover 604
Aerodynamic roof 354
Aerodynamic tubing 360
Aerodynamic underside components 354
Aerodynamic windshield 346
Aerofoil guard 329
"Aero" handlebars 360-361
Aerosol spray fixative 430, 440
"Aerotuck" position 360
Aesculus hippocastanum 130
Aesculus parviflora 137
Afferent arteriole 257
A-frame
  Concorde 416
  Gliders, hang-gliders, and ultralights 426
Africa
  Cretaceous period 72-73
  Earth's physical features 264-265
  Great Rift Valley 60
  Jurassic period 70
  Late Carboniferous period 66
  Middle Ordovician period 64
  Quaternary period 76-77
  Tertiary period 74-75
  Triassic period 68
African elephant 200-201
African plate 59
Aft anchor 395
Aft bogie 615
Aft door 416, 572
Afterbay 314
After breast rope 387
After bridge 395
Afterburner
  Jet engine 418
  Supersonic jetliner 416
Afterburner nozzle 421
Aftercastle
  Sailing warship 377
  Square-rigged ship 375
Aftercastle castle-deck gunport 377
After compass platform 395
After fashion piece 381
After funnel
  Battleship 395
  Iron paddlesteamer 392
Afterpeak 392
After muffler 427
After spring rope 387
Aft fairing 415
Aft galley unit 417
Aft hydroplane 396
Aft main door 414-415
Aft rocker 615
Aft shoulder 560
Aft shroud 612, 613
Aft spar 415
Agate burnisher tip 432
Aggregate fruits 148-149
  Bramble 130
  Development 146-147
Aghulas current 297
Agnatha 178
Agropyron repens 113
Ahead/astern controls 390
Aileron
  ARV light aircraft 424
  BAe-146 components 414
  Curtiss biplane 398-399
  Hawker Tempest components 409
  Lockheed Electra airliner 406
  LVG CVI fighter 405
  Schleicher glider 426
Aileron control wire 403
Aileron hinge strut 403
Aileron mass balance 424
Aileron operating arm 398
Aino Planitia 36-37
Air
  Atmosphere 300
  Oceans and seas 296
  Weather 302-303
Air ambulance 422
Airbag suspension 331
Air bladder 117
Air-brake
  BAe-146 components 415
  Schleicher glider 426
  Tornado 421
Air-brake coupling hose 326
Air-brake jack 421
Air brushes 442
Airbus 380 572-573
Air chamber 118
Air cleaner
  Jaguar V12 engine 345
  Renault Clio 351
Air compression 326
Air-conditioning 496-497
Air-conditioning compressor 344, 354
Air-conditioning duct 417
Air-conditioning pump 344
Air-conditioning refrigerant pipe 344
Air-cooled engine
  Motorcycle engine 366
  V8 engine 404
Air cooling baffle 402
Air cooling fan 427
Air cooling scoop 365
Air-cushioned sole 543
Air data probe 420
Air exit 592
Air filter
  Bell-47 helicopter 422
  Harley Davidson FLHS Electra Glide 363
  Pegasus Quasar
  Volkswagen Beetle 340
  ultralight 427
Air hose 442
Air impingement starter 418
Air inlet
  Jaguar V12 engine 345
  Power drill 601
Air intake
  Concorde, the 416
  Double-decker tour bus 333
  Formula One race car 356, 357
  Lockheed Electra airliner 406
  MCW Metrobus 332-333
  Modern military aircraft 420-421
  Single-decker bus 333
  Turbojet engine 418
  Turboprop engine 419
  Vacuum cleaner 592, 593
Air intake box 425
Air-intake duct 354, 573
Air intake vent 341
Air mass 296
Air outlet 356, 427
Air passage
  Lambeosaurus 99
  Parasaurolophus 99
Air pistol 548-549
Air plants 162
Air pressure 303
Air pump
  Oscillating steam engine 391
  Steamboat 391
Air reservoir valve 327
Air resistance 552
Air rifle shooting 548
Air sac
  Chicken's egg 192
  Scots pine 122
Air scoop
  ARV Super 2 424
  Volkswagen Beetle 340
Air spaces
  Clubmoss stem 120
  Mare's tail stem 135
  Moss 119
  Root 132
  Stem 135
  Wetland plants 158-159
Airspeed-indicator tube
  ARV light aircraft 425
  BE 2B wings 404
Airspeed pitot tube 404
Air taxi 422
Air temperature 300
Air temperature probe
  BAe-146 components 412
  Bell Jetranger helicopter 423
Air vent
  Bicycle helmet 360
  Hockey helmet 540
  Suzuki RGV500 368-369
Air ventilator inlet 405
Aisle
  Airbus 380 572
  Ancient Egyptian temple 458
  Cathedral dome 484
  Gothic church 470, 472-473
  Medieval church 468-469
Akna Montes 37
Ala 213, 223
Alar groove 213
Alarm vibrator motor 558
Alba Fossae 43
Alba Patera 43
Albategnius 40
Albertosaurus 84
Albireo 20
Albumen 192
Albumen gland 177
Alcohol fermentation 313
Alcor 19
Alcyone 20
Aldebaran 18, 21
Alderamin 19
Alethopteris 67, 278
Algae 56, 112, 116-117
  Desmid 112
  Earth's evolution 56
  Fossil record 279
  Lichen symbiote 114
Algal cell 114
Algal layer 114
Algebra 621
Algedi 20
Algenib 19, 20
Algieba 18
Algol 19, 20
Alhambra 488
Alhena 18, 21
Alicante 450
Alidade 377
Alimentary canal 248-249
Alioth 18
  The Big Dipper 19
Alkaid 18
  The Big Dipper 19
Alkali metals 310
Allantoic fluid 192
Allantois 192-193
All-around bicycle 360
"All clear" position 330
All-enclosing fairing 369
Alley 544-545
Alligator 186
Allison 250-C20J turboshaft engine 423
Allium sp. 143
Allosaurus 71, 85
Allotropes 311
Alloy disc 517
Alloy frame 368
Alloy wheel
  Formula One race car 356, 357
  Honda VF750 364-365
  Renault Clio 350-351
  Suzuki RGV500 368-369
All-terrain bicycle 358
Alluvial cone 282
Alluvial fan 282
Alluvium-filled basin 282
Almach 19, 20
  Pegasus and Andromeda 19
Al Nair 19, 20
Alnilam 18
Alnitak
  Horsehead Nebula 16
  Orion 18
Alouatta seniculus 203
Alpha Centauri 21
Alpha Hydri 20
Alpha Mensae 20
Alphard 18, 21
Alpha Regio 36-37
Alpha ring 48
Alphecca 18, 21
Alpheratz 19, 20
  Pegasus and Andromeda 19
Alphonsus 40
Alpine skiing 552-553
Alps 60, 265

Alrami 21
Alsatian dog 195
Alstroemeria aurea 129
Altair 19, 20
Altar 470
Alternating current 328
Alternative engines 346-347
Alternator
  Diesel train 326
  Ford V6 12-valve engine 344
  Jaguar V12 engine 345
  NPT 301 turbojet 418
  Renault Clio 351
Alternator belt 351
Altitude scale 377
Alto clef 502
Altocumulus cloud 302
Alto mute 507
Altostratus cloud 302
Alto voice 502
Aludra 21
Alula 191
Aluminum 311
  Earth's composition 39
  Earth's crust 58
Aluminum alloy backing 346
Aluminum arrow shaft 548
Aluminum beam 560
Aluminum bonnet 354
Aluminum cowl 401
Aluminum flush-riveted skin 407
Aluminum gearbox casing 366
Aluminum racket 544
Aluminum shield 612
Aluminum wheel 406, 615
Aluminum wire figure 455
Alveolar artery and vein 247
Alveolar bone 247
Alveoli 254-255
Amaryllis 155
Amateur rules 532
Amazon Basin 39
Amazon Kindle e-reader 569
Amazon River 264
Amazonis Planitia 43
Ambiens muscle
  Albertosaurus 84
  Iguanodon 97
Ambulacral groove 79, 175
Ambulatory corridor 465
Amelodentinal junction 247
American alligator 186
American beaver 197
American black bear 195
American squash court 545
American squash game 544
Americium 311
Ammonia
  Jupiter's atmosphere 45
  Saturn's atmosphere 47
  Structure of Neptune 51
  Structure of Uranus 49
Ammonite 278-279
Ammonite shell 267
Ammonium dichromate 312
Ammonium hydrosulfide
  Jupiter's atmosphere 45
  Saturn's atmosphere 47
Ammophila arenaria 113
Ammunition 548-549
Ammunition box 408
Amnion 192-193, 260
Amniotic egg 80
Amniotic fluid 192, 260
Amniotic sac 260
Amoebocyte 166
Amphibia 182
Amphibian 80-81, 182-183
  Earth's evolution 56
  Fossil 278-279
  Primitive 68-69, 78
Amphibole 275
Amphitheater 464-465
Amplification
  Drums 518
  Electronic instruments 520
  Guitar 512
  Stringed instruments 510
  Vibraphone 516
  Xylophone 516
Amplifier 520
Amps 316
Ampulla
  Ear 242-243
  Fallopian tube 258-259
  Sea urchin 175
  Starfish 174
Ampullar nerve 242
Anal canal 249
Anal clasper 169
Anal fin
  Bony fish 180-181
  Lamprey 178
Anal fin ray 180
Anal flap 200
Analog signals 580
Anal sphincter muscle 249
Anchisaurus 88-89
Anchor
  74-gun ship 380
  BAe-146 components 412, 414
  Battleship 394-395
  Frigate 397
  Junk 376
  Roman corbita 372
  Square-rigged ship 375
  Tea clipper 392
  Types 386
  Wooden sailing ship 379
Anchor bearing 413
Anchor buoy 379
Anchor cable
  74-gun ship 380
  Sailing warship 376
Anchor chain 386, 395
Anchoring 386-387
Anchor-joint 492
Anchor rode 372
Anchor rope 372-373
Ancient Egyptian building 458-459
Ancient Greek building 460-461, 462
Ancient Greeks 542
Ancient Roman building 462-465, 474
Ancillary drive belt 347
Ancillary drive pulley 345
Ancorale 372
Andamenti 451
Andes
  Cretaceous period 73
  Earth's external features 39
  Jurassic period 71
  Quaternary period 77
  Satellite map 264
  Tertiary period 75
  Triassic period 69
Androecium 140-141, 143
Andromeda 19, 20
Andromeda Galaxy 14, 19
Anemometer 605
Anemonia viridis 166
Anemophilous pollination 144
Angiogram 214
Angiospermophyta 112, 126
Angiosperms 279
Angle bar 393
Angle buttress 471, 472
Angle-of-attack probe 420
Anglerfish 180
Angling 562-563
Angoulême Cathedral 468-469
Angular mountain ridge 295
Angular notch 249
Angular process 194
Angular unconformity 276
Anhydrous copper sulfate 313
Animal cloning 607
Animal life
  Electromagnetic radiation 314
  Primitive 78
Animal remains
  Fossils 278
  Sedimentary rocks 276
Animal stances 82
Animals 56, 67, 78
Anions 308
Ankle
  Anchisaurus 89
  Corythosaurus 98
  Edmontonia 95
  Herrerasaurus 86
  Human 211
  Iguanodon 96
  Pachycephalosaurus 100
  Psittacosaurus 103
  Stegoceras 101
  Stegosaurus 92
  Triceratops 102
  Tyrannosaurus 84
Ankle joint
  Brachiosaurus 90
  Diplodocus 90
  Euoplocephalus 94
  Human 219
  Parasaurolophus 98
  Plateosaurus 88
  Stegoceras 101
  Struthiomimus 87
  Triceratops 102
  Tyrannosaurus 84
Ankylosaurs 83, 92, 94-95
Anne's Spot 47
Annual growth ring 125
Annuals 128
Annular river drainage 288
Annular tendon 241
Annulet 460
Annulus
  Fern 121
  Mushroom 115
Annulus of trunk 201
Ant 168
Anta 461
Antarala 490-491
Antarctica
  Cretaceous period 72-73
  Earth's physical features 264-265
  Jurassic period 70
  Late Carboniferous period 66
  Quaternary period 76-77
  Tertiary period 74-75
  Triassic period 68
Antarctic Circle
  Satellite map 265
  Surface currents 297
Antarctic circumpolar current 296
Antares 18, 21
Antefixa 461
Antelope 198
Antenna
  Airbus 380 573
  Battleship 395
  Crab 172
  Crayfish 173
  Frigate 397
  Global positioning system 590, 591
  Insects 168-169
  Malacostraca 172
  Roman corbita 372-373
  Shrimp 172
  Volleyball net 534
Antennule 173
Anterior antebrachial muscle 86
Anterior aorta 170
Anterior arch 222
Anterior brachial muscle
  Brachiosaurus 91
  Gallimimus 86
Anterior branch of spinal nerve 223
Anterior chamber 241
Anterior chamber of cloaca 185
Anterior crural muscle
  Brachiosaurus 90
  Gallimimus 86
Anterior dorsal fin
  Bony fish 181
  Dogfish 179
  Lamprey 178
Anterior fontanelle 220
Anterior horn 223
Anterior median fissure 223, 238
Anterior median vein 253
Anterior nasal spine 220-221
Anterior petal 141
Anterior root 238
Anterior semicircular canal 243
Anterior sepal 141
Anterior tentacle 177
Anterior tibial artery 253
Anterior tibial muscle
  Albertosaurus 84
  Iguanodon 97
Anterior tubercle 222
Anterior wing of shell 176
Antheridium 117
  Fern 121
  Moss 119
Antherozoids 116-117
  Fern 121
  Moss 119
Anthers 140-143, 145
  Dicotyledons 126-127
  Fertilization 146-147
  Pollination process 144-145
Anthozoa 166
Anthracite coal 280
Anthriscus sp. 135
Anthropoids 202
Anthurium andreanum 143
Antibodies 253
Anticlinal fold 60
Anticline 60-61, 62
Anticline trap 280-281
Anticlinorium 61
Anti-collision beacon 422-423
Anti-corrosion paint 413
Anticyclonic storm system
  Cloud features of Neptune 50
  Jupiter 44-45
  Structure of Saturn 47
Anti-friction pad 552
Anti-glare lens 553
Anti-glare screen surface 584
Antihelix 242
Anti-lift bracing wire
  Avro triplane 403
  Blackburn monoplane 401
  Blériot XI monoplane 401
  LVG CVI fighter 405
Anti-lift wire 399
Antimacassar 329
Antimony 311
Antipodal cell 147
Anti-reflective coating 605
Anti-reverse drive 562
Anti-roll bar
  Renault Clio 350-351
  Volkswagen Beetle 340
Anti-submarine torpedo tube 397
Anti-surge baffle 344
Anti-torque tail rotor 423
Antitragus 242
Anti-vibration engine mount 411
Antler hammer 109
Antler harpoon 109
Antlia 18, 21
Antoniadi 41
Antorbital fenestra
  Baryonyx 83
  Camarasaurus 91
  Diplodocus 90
  Plateosaurus 88
Anura 182
Anus
  Barnacle 173
  Bony fish 181
  Butterfly 169
  Cow 198
  Crayfish 173
  Dolphin 205
  Domestic cat 195
  Elephant 200
  Human 249, 258, 261
  Octopus 176
  Rabbit 196
  Sea urchin 175
  Snail 177
  Spider 170
  Starfish 174
  Tortoise 187
Anvil 242
Aorta
  Anterior 170
  Bony fish 181
  Dogfish 179
  Dolphin 205
  Dorsal 179, 181, 182
  Human 215, 250-251, 252, 255, 256-257
  Posterior 170
  Spider 170
  Ventral 179
Apatite 271
Ape 108, 202-203
Aperture 610, 612, 613
Aperture door 612, 613
Aperture door mounting 612
Aperture plate 611
Apex
  Beetle wing 168
  Butterfly wing 169
  Calligraphy characters 445
  Clubmoss shoot 120
  Fern frond 121
  Fern pinnule 121
  Horsetail shoot 120
  Leaf 136-137, 154-155
  Lung 255
  Moss 119
  Pegasus XL SE
  Pine shoot 125
  Snail shell 177
  Tongue 244-245
  ultralight 426
Apex wire 426
Aphelion 30-31
Aphrodite Terra 36-37
Apical bud
  Bulb 155
  Pine shoot 125
Apical foramen 247
Apical meristem 134
Apical notch
  Seaweed 116
  Thalloid liverwort 118
Apollo 41
Apomixis 146
Apophysis 119
Apothecium 114
Appalachian mountains
  Late Cretaceous period 67
  Mountain building 62
  Quaternary period 77
  Satellite map 264
  Tertiary period 75
  Triassic period 69
Apparent magnitude 22
Appendix
  Chimpanzee 202
  Human 249
  Rabbit 196
Appendix orifice 249
Apple 148-149
Apple iMac 567
Apple iPad 568-569
Apple Macintosh PCs 566
Approach 543
Apse 465, 469, 481
Aquarius 19, 20
Aquatic mammals 104
Aqueduct 236
Aqueous humor 241
Aquiclude 292
Aquifer 292
Aquiferous system 166
Aquila 19, 20
Ara 20
Ara ararauna 190
Arabesque
  Islamic building 488-489
  Neoclassical molding 480
Arabia
  Cretaceous period 72
  Jurassic period 70
Arabian Desert 265
Arabic number system 591
Arachnids 170-171
Arachnoid granulation 237
Arachnoid mater 237, 240
Aral Sea 265
Araneae 170
Araucaria araucana 68
Arcade
  Ancient Roman building 464-465
  Baroque church 479-481
  Gothic building 470-471
  Medieval church 468-469
  Twentieth-century building 495
Arcadia Planitia 43
Arch 484-485
  Ancient Roman building 462, 464-465
  Asian building 490-491
  Baroque church 479, 480
  Calligraphy characters 445
  Cathedral dome 487
  Features of a coastline 295
  French temple 484-485
  Gothic church 470-473
  High jump 543
  Islamic building 488-489
  Medieval building 466-469
  Nineteenth-century building 492-493
  Renaissance building 474-475
Archaeopteryx 57, 84, 85
Arched brace 473

Arched doorway 474, 475
Arched facade 493
Archegoniophore 118
Archegonium
  Fern 121
  Liverwort 118
  Moss 119
  Scots pine 122
Archery 548-549
Archery screen 377
Archimedes 40
Architrave
  Ancient Egyptian temple 458-459
  Ancient Greek temple 461
  Ancient Roman building 463, 465
  Baroque church 479-481
  French temple 485
  Gothic building 473
  Neoclassical building 478, 482-483
  Renaissance building 476-477
Archivolt
  Baroque church 479, 481
  French temple 485
  Gothic church 471
  Medieval building 467-468
  Renaissance building 477
Arch of aorta 253
Arch of Titus 463
Arch-plate 493
Archway 493
  Medieval church 469
  Molding 485
Arctic Circle
  Satellite map 265
  Surface currents 297
Arctic Ocean 265
Arcturus 18, 21
  Hertzsprung-Russell diagram 23
Area measurements 590
Areas 622, 623
Areola 160
Areole 156
Arête 286-287
Argentina 331
Argon
  Atmospheric composition 301
  Mars' atmosphere 43
  Mercury's atmosphere 35
  Periodic table 311
  Venus' atmosphere 37
Argyre Planitia 43
Ariel 48
Aries 19, 20
Aril
  Lychee fruit 148
  Yew seed 123
A ring 46-47
Aristarchus 40
Aristillus 40
Aristoteles 40
Arkab Prior 21
Arkansas hone-stone 452
Arm
  74-gun ship 380
  Calligraphy characters 445
  Gorilla 203
  Human 210
  Lion 194
  Roman anchor 372
  Starfish 174
  Volkswagen Beetle 341
Armature
  Power drill motor 600
  Sculpture 452, 454-455
Armature spindle 600
Arm bud 260
Armed sports 556-557
Armor
  Battleship 394
  Gun turret 396
  Ironclad 393
Armored dinosaurs 92
Armored seat back 409
Arm out-in joint 608
Armpit 211, 234
Armpit bight 388
Armrest 329, 407
Arm rotation joint 608
Arms of Brazil 394
Armstand dive 558-559
Arm up-down joint 608
Arrector pili muscle 235
Arricio 434
Arrow head 109
Arse 382
Arsenic 311
Arsia Mons 43
Arsinoitherium 57, 75, 104-105
Art deco style 495
  Twentieth-century building 494, 495
Artemon 372
Arterial system
  Brain 252
  Kidney 256
Arteriole 252
Artery
  Abdominal 173
  Alveolar 247
  Anterior tibial 253
  Axillary 253
  Basilar 252
  Brachial 253
  Central retinal 240
  Common carotid 215, 251, 253
  Common iliac 215, 253, 257
  Coronary 250-251, 253
  Digital 231, 253
  Dorsal metatarsal 253
  Epibranchial 179
  External iliac 215, 225, 253
  Femoral 225, 253
  Gastric 253
  Hepatic 248, 252-253
  Interlobular 256
  Internal carotid 243, 252
  Internal iliac 215, 253
  Lateral plantar 253
  Orbital 179
  Peroneal 253
  Popliteal 253
  Posterior cerebral 252
  Posterior tibial 253
  Pulmonary 182, 251, 253, 254-255
  Pulp 247
  Radial 231, 253
  Renal 256-257
  Splenic 253
  Sternal 173
  Subclavian 215, 251, 253
  Superior mesenteric 253, 256
  Superior thyroid 244
  Testicular 257
  Ulnar 231, 253
  Umbilical 260
  Vertebral 223, 252
Artesian water 292
Arthropoda 168, 170, 172, 278
Articular capsule 232
Articular cavity
  Hip joint 225
  Metatarsophalangeal joint 232
Artificial elements 310
Artificial fly 562-563
Artificial light 319
Artificial lure 563
Artillery loop 389
Artillery wheel 334
Artiodactyla 104, 198-199
Artist's easel 437
Artist's signature 437, 445
Artist's stamp 445
Art nouveau style 495
Arundinaria nitida 131
ARV Super 2 light aircraft 424-425
Arzachel 40
Ascender 445
Ascending aorta 251
Ascending colon 249
Ascraeus Mons 43
Asexual reproduction 154
Ash
  Mountain building 62
  Rock cycle 266
  Volcano 272-273
Ash chute 395
Ash-cinder volcano 272
Ash eruptions 272
Ash head 540
Ashlar 464, 486
ASIMO humanoid 608-609
Asia
  Cretaceous period 72-73
  Earth's physical features 264-265
  Himalaya formation 62-63
  Hominids 108
  Jurassic period 70
  Middle Ordovician period 64
  Quaternary period 76-77
  Tertiary period 74-75
  Triassic period 68
Asian buildings 490-491
Asian elephant 200-201
Asparagus setaceous 64
Ass 198
Association football 524-525
Astatine 311
Asterias rubens 175
Asterina gibbosa 175
Asteroids 52-53
  Solar system 30
Asteroxylon 78-79
Asthenosphere 58-59
Astragal
  Church of the Sorbonne 486
  Ship's shield 395
Astragalus 183
Astrolabe 376, 377
Astronavigation dome 408
Asymmetric ridge 283
Atacama Desert 264
Atalanta Planitia 36
Athletics 542-543
Atlantic Ocean 264-265
  Quaternary period 77
  Tertiary period 75
Atlas
  Baroque building 482
  Horse 199
  Human 222
  Moon 40
Atlas mountains
  Earth's external features 59
  Quaternary period 77
  Satellite map 265
Atmosphere
  Earth 38-39, 64, 300-301
  Jupiter 45
  Mars 43
  Mercury 34-35
  Neptune 51
  Pluto 51
  Saturn 47
  Uranus 49
  Venus 37
  Water cycle 288
Atoll 298-299
Atoll development 299
Atomic mass 309, 310
Atomic number 310
Atomic weight 310
Atoms 306, 308-309, 596
  Chemical properties 310
  Chemical reactions 312
  Periodic table 310
Atrial diastole 250
Atrial systole 251
Atrium
  Hong Kong and Shanghai Bank 498
  Human 215, 250-251
  Sponge 166
Attached column
  Ancient Roman building 465
  Baroque church 480
  Gothic building 473
  Medieval building 468-469
  Neoclassical building 479
Attachment-bracket 424
Attachment clip 575
Attachment lug 404
Attachment plate 424
Attack line 534
Attack radar 420
Attic
  Baroque church 480-481
  Cathedral dome 487
  Neoclassical building 478, 483
Attic vase 372
Attitude control thruster 614
Attraction 316-317
"A" turret 394
Auda 491
Audio clock settings 521
Audio codec chip 587
Audio software sequencer 521
Auditorium 479
Auditory canal 242
Auditory meatus
  Chimpanzee 202
  Seal 204
Auger 374
Augusta National Golf course 546
Aureole 471
Auricle 242
Auricular surface 223
Auriga 18, 21
Aurora 38, 301
Australasia 264-265
Australia
  Cretaceous period 72-73
  Jurassic period 70
  Late Carboniferous period 66
  Middle Ordovician period 64
  Quaternary period 76-77
  Railroad track gauge 331
  Satellite map 265
  Tertiary period 74-75
  Triassic period 68
Australian Desert 265
Australian rules football 524, 528-529
Australopithecus 77, 108
  Lower jaw 107
  Tertiary period 74
Autofeather unit 419
Autogiro 422
Automatic cylinder lubricator 342
Automatic direction-finding aerial 423
Automatic door 328-329
Automatic louvres 602, 603
Automatic pen 444
Automatic Train Protection (ATP) 330
Automobile freight car 327
Autopilot 412
Autumn wood xylem 134
Auxiliary air intake 420-421
Auxiliary generator 327
Auxiliary power unit 417
Auxiliary Power Unit (APU) exhaust 572
Auxiliary power unit inlet 415
Aves 188
Avimimus 87
Avogadro 41
Avro triplane IV 402-403
Avro Tutor biplane 402-403
Away swing bowler 538
Awning 499
Ax 109, 374
Axial gland 175
Axial instrument unit 612
Axial tilt
  Earth 38
  Jupiter 44
  Mars 42
  Mercury 34
  Moon 40
  Neptune 50
  Pluto 51
  Saturn 46
  Uranus 48
  Venus 36
Axilla 211
Axillary artery 253
Axillary bud 134
  Dicotyledon stem 127
  Durmast oak 131
  Leaf scars 154
Axillary vein 253
Axinite 270
Axis
  Azolla sp. 158
  Horse 199
  Human 222
  Seed 152-153
  Pine cone 122
Axis of rotation
  Jupiter 44
  Mars 42
  Mercury 34
  Moon 40
  Neptune 50
  Pluto 51
  Pulsar 28
  Saturn 46
  Uranus 48
  Venus 36
Axle
  Avro triplane 402-403
  Blackburn monoplane 400
  Bus 333
  Curtiss biplane 399
  Honda VF750 365
  Lockheed Electra airliner 407
  LVG CVI fighter 405
  Steam locomotive 324
Axle bolt 425
Axon 239
Aythya fuligula 188
Azimuthal map projection 265
Azo yellow 442
Azurite 306

B

B-17G Flying Fortress bomber 408
Baboon 202
Bach 35
Back
  Block and tackle 383
  Elephant 200
  Horse 198
  Human 210
  Lion 195
Backboard 532
Back bone 222
Back check 514
Back contact grid 605
Background radiation 10
Back/Home button 586
Back judge 526
Back line 535
Back pocket 528
Backrest
  ARV light aircraft 425
  Lockheed Electra passenger seat 407
Backs
  Handball 535
  Hockey 540
  Soccer 524
  Volleyball 534
Backshell 615
Back sight 549
Backstay 378, 379, 380
Backstay stool 381
Back strap 560, 561
Backstroke 558-559
Backup battery 567
Backward defensive stroke 538
Backward dive 558
Backwash 294
Back zones 534
Bacteria 56
Bactrian camel 199
Baculum 144
Badger 194
Badminton 544-545
BAe-146 jetliner components 412-415
Baffin Island 264
Baffle 341
Baffle plate 347
Bage, C. 492
Baggage compartment door 423
Bagneux Church 468-469
Bahada 282
Bail 538
Bail arm 562
Bailey 466
Bail handle 336
Bailly 40
Baird's beaked whale 205
Bait fishing 562
Balaenoptera musculus 205
Balance 232
Balance and muscle coordination 237
Balance weight
  Jaguar VI2 engine 345
  Mid West rotary engine 411
Balancing drilling
  Mid West rotary engine 411
  Wankel rotary engine 347
Balanophyllia regia 167
Balata surface 546
Balcony 493
  Islamic tomb 489
  Nineteenth-century building 493
  Renaissance theater 477
  Rococo style 478, 482
  Sailing ship 378, 379, 381
Baleen whale 204

Ball
  Australian rules football 528
  Baseball 537
  Basketball 533
  Cricket 538
  Football 526
  Gaelic football 528-529
  Golf 546
  Handball 535
  Hockey 540
  Hurling 541
  Lacrosse 541
  Netball 535
  Racketball 545
  Rugby 524, 530-531
  Soccer 524
  Squash 545
  Tennis 544
  Volleyball 534
Ballast 324
Ball bearings 358-359
Ballflowers 470-471
Ball marker 547
Ball size number 525
Baltica 65
Baltimore oriole 193
Baluster
  Asian building 490
  Gothic building 473
  Neoclassical building 483
Balustrade
  Asian building 490
  Baroque church 479-480
  Cathedral dome 487
  Gothic church 472-473
  Neoclassical building 478, 483
  Nineteenth-century building 493
  Renaissance theater 477
  Twentieth-century building 495
Balzac 35
Bamboo 131
Banana 146
Banded ironstone 277
Banded milk snake 184
Bandy 540
Bank of England 482
Banner 375
Bar
  Musical notation 502
  Relief-printing press 449
Bar area 573
Barb
  Angling 562
  Cnidocyte 167
Barberry 130-131
Barbette
  Battleship 394
  Gun turret 396
Bar code 606
Bare end
  Reef knot 388
  Single sheet bend 387
Barium 310
Bark
  Bishop pine stem 125
  Epiphyte 162
  Lichen 114
  Perennials 130-131
  Stem 134
  Woody plants 130-131
Bar keel 392
Barkhan dune 283
Bar line 502
Barnacle 172-173
Barnard's Star 23
Baroque style 478-483
Barosaurus 82
Barred spiral galaxy
  Galaxies 12-15
  Milky Way 14-15
  Objects in universe 11
Origin and expansion of universe 10-11
Barrel
  Gun turret 397
  Wood capstan 387
Barrel joint 508
Barrel vault 484-485
  Ancient Roman building 463-464
  Baroque church 479
  Medieval church 468
  Nineteenth-century building 493
Barrier beach 294
Barrier reef 299
Barry, C. 493
Bars 516-517
Bar swivel 562
Baryonyx 83, 84-85
Baryte 270
Basal disk 167
Basal scale 114
Basalt 274-275
Basaltic lava 272
Bascule 493
Base
  Ancient Greek temple 461
  Ancient Roman building 465, 465
  Asian building 491
  Baroque church 479, 481
  Dome 484, 486, 487
  French temple 485
  Gothic church 470, 472
  Medieval church 469
  Neoclassical building 478, 483
  Renaissance theater 477
  Sheet lead 383
  Twentieth-century building 494
  Twin bollards 386
Baseball 536-537
Base line
  Calligraphy lettering 445
  Tennis 544
Basement 483
Basement membrane of Bowman's capsule 257
Base of phalanx 230
Base plate 552
Bases 536
Basic movements 237
Basic shield volcano 272
Basidium 115
Basilar artery 252
Basilar membrane 243
Basilican system 468
Basilica of St. Madeleine 468
Basilic vein 253
Basket
  Basketball 532
  Ski pole 552-553
Basket arch 472, 484
Basketball 532-533
Basket star 174
Basking shark 179
Bas-relief carving 491
Bass angling 562
Bass bridge
  Concert grand piano 515
  Upright piano 514
Bass clarinet 504
Bass clef 502
Bass drum 504-505, 518-519
Bass formation 277
Bass joint 508
Bass notes 512
Bassoon 503, 504-505, 508
Bass/Play mode 586
Bass voice 502
Bastille 466
Bat
  Baseball 537
  Cricket 539
Bat (animal) 105
Batholiths 274-275
Batsman 538-539
Batten
  74-gun ship 381
  Junk 376
  Wall construction 602
Batter 536-537
Battery
  Bell-47 helicopter 422
  Bersey electric cab 342
  Digital video camera 582
  Hubble Space Telescope 613
  Inverter 355
  Kirby BSA racing sidecar 369
  Battery assembly 355
Battery box 327, 424
Battery carrier 338
Battery compartment 407
Battery cover 579
Battery cooling fan 355
Battery electronic control module (ECM) 355
Battery overspill 422
Battery strap 339
Batting gloves
  Baseball 537
  Cricket 539
Battlemented cornice 471
Battlements 466-467
Battleship 394-395
Bauxite 268
Bay
  Building 468, 469, 494
  Coastline features 295
  River features 291
Bay-head beach 294
Bay-leaf garland 480
Bayonet fixing 352
Bay window 477
BE 2B bomber 404-405
Beach
  Coastline 294-295
  River development 289
Beacon 407, 422-423
Beaded edge tire 336
Beadlet anemone 166
Bead molding 459
Beak
  Ankylosaurus 94
  Attic vase 372
  Bird 188-190
  Ceratopsian 100
  Chelonian 186
  Dolphin 204
  Euoplocephalus 94
  Hatching chick 192-193
  Iguanodon 97
  Moss 119
  Octopus 176
  Ornithopod 96
  Panoplosaurus 94
  Protoceratops 102
  Psittacosaurus 103
  Stegosaurus 92
Beaked whale 204
Beaker 312
Beam
  BAe-146 jetliner 414
  Gothic church 473
  High-tension 496
  Iron paddlesteamer 393
  Modern building 497-499
  Nineteenth-century building 492
  Single skull 560
Bean
  Black 153
  Broad 152
Bear 104, 106, 194-195
Bearing
  Electric generator 317
  Jaguar V12 engine 345
  Motorcycle gearbox 366
  Rotary engine output shaft 411
Bearing assembly 425
Bearing housing 344
Bearing mount 411
Bearing seal 359
Bearing sleeve 338
"Beast feet" 84
Beaten gold 432
Beaters 516, 518-519
Beats 502
Beaver 196-197
Becket 383
Becket Chapel 467
Bed
  Relief printing press 449
  Sedimentary rocks 276
Bedding plane
  Cave system 285
  Coastline 294-295
Bedford cord upholstery 336
Bedplate 390
Bedrock 298
  Delta formation 291
Bee 168, 379
Bee hummingbird 193
Bee pollination 144-145
Beeswax 384
Beethoven 35
Beetle 168
Begonia 129, 155
Begonia x tuberhybrida 129, 155
Behavior 108, 237
Belaying pin 382
Belemnites 71, 278-279
Belfry
  74-gun ship 380
  Church of St. George in the East 481
Bell 508
Bell 206 Jetranger 423
Bell 47G-3B1 422-423
Bellatrix 18
Bell chamber 493
Bell crank 391
Bell housing 347
Bell joint 508
Bello 35
Bell Regio
  Radar map of Venus 36
  Structure of Venus 37
Belly
  Bird 188
  Caiman 186
  Dolphin 204
  Elephant 201
  Horse 198
  Lion 195
  Lizard 184
  Sail 384
  Viola 511
  Violin 510
Belly-band 555
Belly fairing 572
Belt
  Jupiter 44-45
  Structure of Saturn 47
Belt armor 394
Belt color 556
Belt drive 366
Belt pulley 345
Belt tensioner 344, 364
Belvedere 476
Bench officials
  Ice hockey 550
  Lacrosse 541
Bending 318
Bends 387
Benguela current 297
  Satellite map 264
Benz, Karl 334
Benz Motorwagen 335
Benz six-cylinder engine 405
Berardius bairdi 205
Berberis sp. 130-131
Berkelium 311
Berries 148-149
Bersey electric cab 342
Berthing ropes 387
Beryl 270
Beryllium 310
Beta Hydri 20
Beta Mensae 20
Beta Pictoris 21
Beta ring 48
Betelgeuse 18, 21
  Hertzsprung-Russell diagram 23
  Orion 18
  Universe 10-11
Betula grossa 74
Betula lenta 76
Betulites 74
Bevel gear 335
Bevel pinion 338
Beverley Minster 484
Bezel 584
Bhagirathi Parbat 62
Bianco di San Giovanni 434-435
Biathlon rifle 549
Bib 557
Bi-block engine 337
Biceps brachii muscle 226
Biceps femoris muscle 227
Bicycle 360-361
Bicycle anatomy 358-359
Bicycle riding 315
Biennials 128
Biflagellate cell 116
Bifurcate ligament 232
"Big Ben" 493
Bigbore rifle shooting 548-549
Big end
  Flat-four cylinder arrangement 340
  Four-stroke cycle 343
  Jaguar straight six engine 344
  Mid West engine 410
  Trojan engine 342
Big-end bearing 335
Bight 388
Big toe 232-233
Bile duct 189, 249
Bilge keel 395, 397
Bilge keelson 393
Bill
  Danforth anchor 386
  Running block 383
  Sail hook 384
Bilobed leaves 123
Bin base 592
Bin cover handle 593
Bin cover retaining clip 592, 593
Binder 464
Binder bolt 361
Binding 383
  Acoustic guitar 512
  Iron paddlesteamer 392
Binding medium 440
Bin handle 592
Bin handle clip 592
Bin lower seal 592
Binnacle box 378
Binocular eyepieces 610, 611
Bin upper seal 592
Bin upper seal seating 592
Biology symbols 591, 621
Bipedal dinosaur 84, 96, 100
Bipinnate leaf 137
Biplane elevator 398-399
Biplanes 402-403, 408
Bipolar neuron 259
Birch 74, 76
Bird 84, 188-191
  Beak 190
  Earth's evolution 57
  Feathers 191
  Feet 190
  Fossil record 279
  Wing 191
"Bird feet" 96
Bird-hipped dinosaur 82, 92, 96
Bird of prey 188
Bird pollination 144
Bishop pine 124-125
Bismuth 281, 311
Bit 601
Biternate leaves 137
Bit-guard 555
Bitt
  74-gun ship 380-381
  Roman corbita 373
Bitter end, Hawser 387
Bituminous coal 280
Bivalves 79, 176, 278-279
Blackbacked gull 193
Black bean 153
Black belt 556
Blackberry 130, 146-147
Blackberry Curve 8520 589
Blackburn monoplane 400-401
Blackburn, Robert 400
Black dwarf 24-25
Blackheaded gull 189
Black ink cartridge 574
Black ink-cartridge clamp 574
Black holes 28-29
  Galaxies 12
  Massive stars 26-27
Black Mesa 277
Black rhinoceros 199
Black Sea 265
Blackstonia perfoliata 144
Black walnut 137
Black widow spider 171
Bladder
  Bony fish 181
  Chimpanzee 202
  Dolphin 205
  Domestic cat 195
  Elephant 200
  Human 215, 257, 258-259, 261
  Lizard 185
  Rabbit 196
  Soccer ball 525
  Swim 178, 180-181
  Tortoise 187
  Urinary 181
Bladder wrack 117
Blade
  Butterwort 161
  Calligraphy drawing board 445
  Danforth anchor 386
  Dicotyledon leaf 127
  Fencing foil 557
  Golf clubs 547
  Hockey stick 540
  Kayak paddle 560
  Leaf surfaces 136, 138
  Monocotyledon leaf 127
  Propeller 390
  Roman rudder 373
  Sculling oar 560
  Seaweed 116-117
  Vegetative reproduction 154
  Venus fly trap 160
  Volkswagen Beetle 341
  Wetland plants 158-159
  Wind turbine 604
Blade bearing 604
Blade counterweight 406, 422
Blade hub 604
Blade pitch control 604
Blade-root attachment 422-423

Blade tip sealing shroud 419
Blanking plate 411
Blast bag 396
Blaslocyst 607
Blast-pipe 325
Blending 440
Blériot XI monoplane 401
Blériot, Louis
  Early monoplane 400
  Pioneers of flight 398
Blindage 377
Blind arch
  Asian building 491
  Cathedral dome 487
  Gothic church 470
Blind door 478
Blind pull 336-337
Blind release bar 552
Blinds 603
Blind-side prop 530
Blind spot 241
Blind tracery 493
Blind trefoil 473
Blind window 478
Block and tackle 382-383
Block carving 470
Block cube 270
Block disintegration 282
Block-fault lake 293
Block-fault mountain 62
Blocking pad 550
Blocks 310
Blood cells 253
Blood clotting 253
Blower control 325
Blower isolator valve 325
Blow hole 508
Blowhole 205
Blubber 204
Blue-and-yellow macaw 190
Blue cell 584
Blue-green alga 56, 78
Blue light 318
Blue line 550
Blue supergiant star
  Hertzsprung-Russell diagram 23
  Stellar black hole 29
Blue whale 204-205
Bluff 289
Blunt button 556-557
Blu-ray player 584
BMW R/60 motorcycle 362
Board
  Ice hockey rink 550
  Modeling 455
  Pastels 441
Boarding 464
Board mounting 450-451
Boat boom 395
Boatbuilder's tools 374
Boat handling derrick 395
Boat slide 378
Boat winch 394
Bobstay 379
Body
  Anchisaurus 89
  Discus 542
  Dunkeld wet fly 563
  Motorcycle 364-365
  Sauropodomorpha 88
  Stringed instruments 510
Body bag 426
Body cells 216-217
Body cradle 398
Body drop 556
Body joint
  Flute 508
  Piccolo 508
Body landing gear 572
Body mount 338
Body organs 214-215
Body padding 526
Body sections
  Insect 168
  Scorpion 170
  Spider 170-171
Body shell 518-519
Bodyshell
  Renault Clio 348-349
  Volkswagen Beetle 341
Body tackles 528
Body temperature regulation
  Dinosaurs 92
  Mammals 104
Body wire 557
Bodywork 348-349
  Race cars 356
  Volkswagen Beetle 341
Bodywork mounting point 364
Boeing 747-400 412
Bogie axle 326
Bogie frame 325
Bogie main landing gear 416
Bogie wheel strut 615
Boiler
  Box boiler 392
  Donkey boiler 392
  Steamboat with paddle wheels 391
  Steam locomotives 324-325
Boiler pressure gauge 325
Boiler water level 325
Bole base 432-433
Bollard
  Battleship 395
  Frigate 397
  Mooring and anchoring 386-387
Bolson 282
Bolster 378
Bolt
  Church of St. Pierre 499
  Lower deadeye 383
  Shackle 386
  Toaster 598
Bolted anchor 425
Bolt hole
  Drum brake 365
  Mid West rotary engine 411
  Twin bollards 387
Bolt rest 548
Bolt rope 372, 384
Bolts 548-549
Bomb 404, 408
Bomb aimer's viewing panel 408
Bomb door 408
Bomber
  Modern military aircraft 420
  World War I aircraft 404-405
  World War II aircraft 408-409
Bomb rack 404
Bonaventure mast 377
Bonaventure topcastle 377
Bonaventure topmast 377
Bonaventure top yard 377
Bonaventure yard 377
Bonded brick wall 492
Bonding
  Chemical reactions 312
  Covalent 309
  English bond 485
  Gases 307
  Ionic 308
  Liquids 307
Bone cell 217, 225
Bone marrow smear 225
Bones
  Fossil 278
  Human 224-225, 230, 232
Bone structure 108
Bone surface 807
Bony crest
  Baryonyx 83
  Corythosaurus 98
  Lambeosaurus 99
  Parasaurolophus 99
Bony dorsal shield 78
Bony fish 180-181
Bony frill 100
Bony nodule
  Pachycephalosaurus 100
  Prenocephale 100
Bony ridge 100
Bony shelf 100, 101
Bony spike 100
Bony strut 83
Bony studs 92
Bony tendons 96
Boom
  Battleship 394-395
  Curtiss Model-D pusher 399
  Double topsail schooner 385
  Guest boat boom 394
  Hong Kong and Shanghai Bank 498
  Longboat 380
  Rigging 382
  Sailing dinghy 561
Boom guy block 382
Boomkin 380
Bootes 18, 21
Bordino Steam Carriage 334-335
Borealis Planitia 35
Borneo 265
Boron 311
Boss
  Church roof 468-469
  Hurley 541
  Viking karv 374
Bothriolepididae 65
Botryoidal habit 270-271
Bottom ballast 377
Bottom bracket 358
Bottom hose 351
Bottom plate 390, 392-393
Bottom race 359
Bottomset strata 283
Boudin 60-61
Boulder beach 295
Boulder clay 286
Bounce pass 535
Boundary
  Cricket 538
  Mantle crust 39
  Outer core-mantle 39
Boundary line
  Australian rules football 528
  Badminton 545
  Cricket 538
  Squash 545
Bow
  74-gun ship 381
  Kayak 560
  Sailing dinghy 561
  Stringed instruments 510
  Wooden sailing ship 378
Bowball 561
Bow drill 109
Bower anchor
  Battleship 395
  Sailing warship 377
  Wooden sailing ship 379
Bow front 483
Bowl 445
Bowler 538
Bowline 388, 389
Bowling crease 538
Bowman's capsule 256
Bowman's space 257
Bow ornament 375
Bowpost 561
Bows 548
Bow section 392
Bow-side oar 560
Bowsprit
  Iron paddlesteamer 393
  Longboat 380
  Rigging 382
  Sailing warship 376
  Tea clipper 392
  Wooden sailing ship 378-379
Bowsprit cap 382
Bowtell molding 475
Box 477
Box boiler 392
Box fold 61
Box freight car 327
Boxing 556
Box-leaved milkwort 144
Box-section tubular cradle frame 364
Box sister keelson 393
Boxwood staff 377
Brace
  Asian building 490
  Barrel vault 485
  Dome 486
  Double topsail schooner 385
  "Ellerman Lines" steam locomotive 324
  Gothic building 473
  Neoclassical building 479
  Nineteenth-century building 493
  Roman corbita 372
  Sailing warship 377
  Trombone 506
  Wooden sailing ship 378
Brace-and-bit 600-601
Brace block 373
Bracer 548
Brachial artery 253
Brachialis muscle 226
Brachial plexus 238
Brachial valve 278
Brachiocephalic trunk 251
Brachiocephalic vein 253
Brachiopods 278-279
Brachioradialis muscle 226
Brachiosaurus 88, 90-91
Brachylophosaurus 98
Bracing 513
Bracing cable 427
Bracing strut 401-402, 423
Bracing tube 364
Bracing wire
  Blériot XI monoplane 401
  LVG CVI fighter 405
  Wright Flyer 399
Bracken 121
Bracket
  Baroque church 479
  Cathedral dome 484
  Gothic building 473
  Islamic tomb 489
  Medieval building 466
  Neoclassical building 478
  Renaissance building 475
Bracket shell 58
Bracteoles
  Dehiscent fruit 151
  Ice-plant 129
  Live-forever 129
Bracts 141-143
  Bromeliad 113
  Dicotyledon flower 127
  Durmast oak 131
  Florists' *chrysanthemum* 129
  Guzmania lingulata 163
  Ice-plant 129
  Indehiscent fruit 150
  Live-forever 129
  Peruvian lily 129
  Rose 131
  Slender thistle 129
  Wind-pollinated plant 144
Bract scales 122
Braided polyester 388
Braided stream 286
Braiding
  Dragon prowhead 374
  River features 290
Brailing rope 372
Brail line 372
Brain
  Bird 189
  Bony fish 181
  Butterfly 169
  Chimpanzee 202
  Crayfish 173
  Dogfish 179
  Dolphin 205
  Domestic cat 195
  Elephant 200
  Hominid 108
  Human 236-237
  Lizard 185
  Octopus 176
  Rabbit 196
  Spider 170
Braincase 108
Brain cavity 100
Brainstem 236
Brake 332, 350
Brake actuating chain 327
Brake arm 552
Brake back plate 340, 350
Brake block 360
Brake bridge 361
Brake cable 365
Brake calliper
  ARV light aircraft 424
  Disc brake 365
  Harley-Davidson FLHS Electra Glide 363
  Honda VF750 364-365
  Husqvarna Motocross TC610 368
  Renault Clio 351
  Suzuki RGV500 368-369
  Wagon bogie 331
Brake cylinder 327, 350-351
Brake disc
  ARV light aircraft 424
  Renault Clio 351
  Wagon bogie 331
Brake drum 339-340, 342
Brake duct 357
Brake fluid 365
Brake hose 351
Brakeless wheel hub 369
Brake lever
  ARV light aircraft 425
  Benz Motorwagen 335
  Bicycle 359
  Eddy Merckx racing bicycle 361
  Harley-Davidson FLHS Electra Glide 363
  Kirby BSA 369
  Suzuki RGV500 369
  White Steam Car 342
  "Windcheetah" racing HPV bicycle 361
Brake master cylinder
  Harley-Davidson FLHS Electra Glide 363
  Honda VF750 364
  Suzuki RGV500 368
Brake mount 424
Brake pad
  Disc brake 365
  Eddy Merckx racing bicycle 361
  Renault Clio 351
  Wagon bogie 331
Brake pedal
  Harley-Davidson FLHS Electra Glide 363
  Honda VF750 364
  Oldsmobile bodywork 337
  Renault Clio 350
  Steam-powered Cugnot 334
  Suzuki RGV500 368
Brake pipe
  ARV light aircraft 424
  BAe-146 components 414
  Lockheed Electra airliner 406-407
Brake pivot bolt 361
Brake plate 365
Brake quadrant 335
Brake rigging
  British Rail Class 20 diesel engine 327
  "Ellerman Lines" steam locomotive 324-325
Brake rod 337, 339
Brake servo 351
Brake shield 351
Brake shoe 330
  "Deltic" diesel-electric locomotive 327
  Drum brake 365
  "Ellerman Lines" steam locomotive 325
  Renault Clio 350
Brake slip 395
Brake torque arm 364
Brake vacuum pump 324
Braking
  Motorcycle 364
  Train 330
Braking control system 330
Braking distance 331
Bramante 35
Bramble 130, 146-147
Branched leaf venation 127
Branches
  Bishop pine 124
  Clubmoss 120
  Crab cactus 129
  Dicotyledons 127
  Horsetail 120
  Perennials 130-131
  Seaweed 117
  Sporophore 114
  Woody plants 130-131
Branchial heart 176
Branching bracteole 151
Branchiostegal ray 181
Branchlet 114
Branch trace 125
Brassavola nodosa 162
Brass bevel 336-337
Brass housing for ignition cable 343
Brassica sp. 132
Brass instruments 504-505, 506-507
Brazil 331
Brazilian battleship 394-395
Brazilian current 296
Brazilian Highlands 264
Bread 598
Breakfast room 483
Breakwater
  Battleship 395
  Frigate 397
  Single scull 561
Breast
  Bird 188
  Horse 199
  Human 211
Breast auger 374
Breast bone 218
Breast stroke 558-559
Breastwork 380
Breather paper 602
Breather pipe 422
Breccia 276-277
Breech 596
Breech block 396
Breeches 557
Breech wheel 396
Breve rest 502
Brick arch 324
Brick pier 495
Brick vault 492

Brick wall 492
Bridge
  Acoustic guitar 512-513
  Battleship 394-395
  Cello 511
  Double bass 511
  Electric guitar 513
  Frigate 397
  Golf course 546
  London Bridge 466-467
  Medieval castle 467
  Modern building 498
  Viola 511
  Violin 510
Bridge pin 512
Bridges 330
Bridle 555
Bright Angel shale 277
B ring 46-47
Britain 331
Brittle stars 174-175
Broad ax 374
Broadcom Persona tablet 569
Broad disk 79
Broad lace trim 336-337
Broadside 378
Broken pediment 481
Bromeliads 112-113
  Epiphytic 162-163
Bromine 311
Bronchi 254
Bronchial nerve 254
Bronchial tree 254
Bronchial vein 254
Bronchiole and alveoli 254
Bronchus
  Frog 182
  Human 215, 255
Bronze casting 452
Bronze finishing tools 454
Bronze mast truck 372
Bronze statue 455
Broomrape 163
Browband 554-555
Brow horn 102
Brow horn core 103
Brown alga 116
Brown scales 121
Brown seaweed 116-117
Brow ridge
  Australopithecus 108
  Gorilla 203
  Homo sapiens 108
Browser menu 577
Brush 432, 444, 600
Brushbar 592, 593
Brushbar drive belt cover 593
Brushbar motor control 593
Brush holder 600
Brushing boot 554
Brush lettering equipment 444
Brush rest 444
Brush tool articulation 593
Bryce Canyon 276
Bryophyta 118
Bryophytes 112, 118-119
Bryozoans 279
Bryum sp. 112
Buccal cavity
  Bird 189
  Chimpanzee 202
  Dolphin 205
  Domestic cat 195
  Elephant 200
  Pachycephalosaurus 100
  Rabbit 196
  Tortoise 187
Buccal mass 176
Buccinator muscle 229
Bucket seat 361
Bucket tappet 344
Bud
  Adventitious 154
  Aechmea miniata 162
  Apical meristem 134
  Begonia 129
  Bishop pine 124
  Broomrape 163
  Clematis flower 131
  Dicotyledons 127
  Durmast oak 131
  Florists' chrysanthemum 129
  Horse chestnut 130
  Larkspur 141
  Lily 140
  Lime 143
  London plane 134
  Moss 119
  *Oxalis sp.*121
  Pine needle 125
  Rhizome 155
  Root tuber 154-155
  Rose 131
  Rowan twig 131
  Stolon 154
  Water lily 159
Buddhist style 490
Budh Planitia 35
Bud scale
  Bishop pine 124
  Dicotyledon stem 127
  London plane 134
  Pine shoot apex 125
Buffer
  "Deltic" diesel-electric locomotive 327
  "Ellerman Lines" steam locomotive 324-325
  Italian State Railroads Class 402 328
  "Rocket" steam locomotive 324
Buffing pad 328
Bugle 506
Bulb
  Renault Clio 352
  Vegetative reproduction 154-155
Bulb horn
  1906 Renault 337
  Ford Model T 338
Bulbil I54-155
Bulbourethral gland 259
Bulkhead
  ARV Super 2 425
  Flat freight car 327
Bulkhead stiffener 393
Bulkhead trim 407
Bulldog clip 430
Bullet 397, 549
Bullet block 373
Bullet-shaped guard 278
Bull-head rail 331
Bullnose chisel 452
Bull's-eye 549
Bulwark
  74-gun ship 380
  Ironclad 393
Bumblebee 168
Bumper
  Bus 332-333
  Honda Insight 354
  Renault Clio 348-349
  Volkswagen Beetle 341
Bung 313, 560
Bunkers 546-547
Bunk space 397
Bun lamp burner 339
Buntline 372
Buon fresco 434-435
Buoy 379
Buoyant wetland plants 158
Burmese pagoda 490
Burning reaction 312, 313, 315
Burnisher 432, 446
Bursting charge 397
Buses 332-333
Business class cabin 572
Bush 605
Bushes 130-131
Bushing 314
Butt
  Bassoon 508
  Lacrosse crosse 541
  Tennis racket 544
Butt cap 563
Butte
  Igneous rock structures 274
  Weathering and erosion 283
Buttercup 127, 132-133
Butterfly 168
Butterfly knot 389
Butterfly plate 382
Butterfly swimming stroke 558-559
Butterwort 160-161
Butt extension 563
Buttock
  Horse 198
  Human 210
Button head rivet 392
Button-quilted upholstery 336
Buttress 484
  Baroque church 478-481
  Dome 486
  Gothic church 470-473
  Medieval building 466, 468-469
  Nineteenth-century building 493
Butt section 562

C

3C275 (quasar) 11
Caarduus tenuiflorus 129
Cab 324, 327
Cabane strut 404
Cabbage 132
Cab-end bogie 327
Cabin
  74-gun ship 380-381
  Iron paddlesteamer 392-393
  Wooden sailing ship 379
Cabin air-discharge aperture 414
Cabin air duct 417
Cabin air-pressure discharge valve 413
Cabinet rasp 452
Cabin trim 406-407
Cable 600-601
Cable entry point 598
Cable guide 358-359, 360
Cable holder 395
Cable retaining gland 598
Cables and ducting 602
Cable stop 365
Cacti
  Desert survivors 112
  Dryland adaptation 156
  Herbaceous flowering plants 129
Cadmium 311
Cadmium red 436
Cadmium yellow 438
Caecum
  Bird 189
  Brachiosaurus 90
  Chimpanzee 202
  Cow 198
  Digestive 176, 173
  Gut 170
  Human 249
  Octopus 176
  Pyloric 181-174
  Rabbit 196
  Rectal 174
Caelum 18
Caernarvon Castle 466
Caiman 186-187
Calamus 191
Calcanean tendon 232-233
Calcaneum 183, 199
Calcareous ooze 299
Calcareous plates 172
Calcareous tufa 284
Calcite (calcium carbonate)
  Blue chalk 430
  Carbonates 269
  Cave 284-285
  Fossils 278
  Mohs scale 271
  Sedimentary rocks 277
  Testing candle wax 313
Calcite curtain 285
Calcite ossicle 174
Calcite ridge 284-285
Calcium 310
  Earth's composition 39
  Earth's crust 58
  Seawater salt content 296
Calcium line 23
Caldera
  Igneous rock structures 275
  Lake formation 293
  Volcano 272
Caledonian mountains
  Late Carboniferous period 67
  Triassic period 69
Calendars 618
Calf 210
Californian purple sea urchin 175
Californium 311
Calliactis parasitica 166
Calligraphy 444-445
Calliper assembly 365
Callipers 452
Callisto 44
Caloris Basin 34-35
Caloris Montes 35
Calypte helenae 193
Calyptra 119
Calyx 140
  Allium sp. 143
  Centaury 144
  Human 256
  Simple succulent berry 149
Cam 344
Camarasaurus 91
Cambium 126
Cambrian period
  Fossil record 279
  Geological timescale 56
Camcorder 582
Cam cover
  Jaguar straight six engine 344
  Jaguar V12 engine 345
  72° VTO engine 356
Camera module 581
Camellia 137
Camels 198-199
Camera 608, 611
  Digital 580-581
  Digital video 582-583
Camera pouch 426
Cam follower
  Ford diesel engine 347
  Jaguar straight six engine 344
  Jaguar V12 engine 345
  Velocette OHV engine 367
Cam lobe 344
Camouflage 409
Camouflage coloration 192
Campaniform capital 458
Campanile 477
Camptosaurus 70, 97
Camshaft 343-345
Camshaft gear 367
Camshaft sprocket 345
Camshaft timing gear 344
Canada 331
Canadian football 524, 526-527
Canadian pond weed 158-159
Canal
  Sea urchin 175
  Starfish 174
Canals 42
Canaries current 296
Cancel button 575
Cancellous bone 224
Cancer 18, 21
Candelabrum 476
Candle lamp 335
Candle wax 312-313
Canes Venatici 18, 21
Canine tooth
  Bear 106, 194
  Chimpanzee 202
  Human 246
  Hyaenodon 107
  Lion 194
  Opossum 106
  Smilodon 107
  Toxodon 106
Canis familiaris 195
Canis Major 18, 21
Canis Minor 18, 21
Canister 594
Cannon 376, 394
Cannon bone 198-199
Cannondale bicycle 361
Canoeing 560-561
Canopus 15
Canopy
  1906 Renault 336-337
  ARV light aircraft 424-425
  Bell-47 helicopter 422
  Daimler engine 343
  Ford Model T 339
  Hawker Tempest components 409
  Oldsmobile engine 336
  Schleicher glider 426
  Schweizer helicopter 423
Canopy latch 425
Canopy rail 409
Canson paper 441
Cant frame 381
Cantilever beam 494
Cantilever brake 358, 361
Cantilever brake boss 359
Cantilevered shade 495
Cantle
  Racing saddle 555
  Showjumping saddle 554
Canvas
  Acrylic paint 442
  Oil paint 436
  Preparation 437
Canvas shroud 362
Canvas support 437
Canyon
  Sedimentary rocks 276-277
  Weathering and erosion 282-283
Cap
  Alga 116
  Fungus 114-115
  Radicle tip 153
  Wood capstan 387
  Wooden sailing ship 378-379
Capacity measurements 590
Cape gooseberry 149
Capella 18, 21
Cape Royal 277
Capillary fringe 293
Capillary network 254
Capital
  Ancient Egyptian building 458-459
  Ancient Greek building 458, 460-461
  Ancient Roman building 458, 463, 465
  Asian building 490, 491
  Baroque church 479, 481
  Cathedral dome 487
  Domed roof 486
  French temple 485
  Islamic mosque 488
  Medieval building 467-469
  Neoclassical building 478, 483
  Ptolemaic-Roman period 459
  Renaissance building 476-477
  Romanesque style 468
Capitate bone 230
Capitulum 129, 142
Cap line 445
Capricornus 19, 20
Capstan 387
  74-gun ship 380
  Iron paddlesteamer 393
  Wooden sailing ship 379
Capstan screw 514
Capsule
  Dry fruit 150-151
  Moss 112, 119
Captain's cabin 379, 381
Captain's seat 416
Captain's shelter 394
Capybara 196-197
Carapace 172-173, 187
Carbon
  Atomic mass 310
  Bows 548
  Candle wax 312-313
  Coal formation 280
  Minerals 268
  Periodic table 311
  Small stars 24-25
  Structure of red supergiant 26
Carbonates 269
Carbon atom 138
Carbon bush 605
Carbon dioxide
  Earth's atmosphere 300
  Gas 312-313
  Mars' atmosphere 43
  Photosynthesis 138
  Respiratory system 255
  Scrubber compartment 397
  Structure of comet 53
  Venus' atmosphere 37
Carbon graphite racket 544
Carbonic acid 284
Carboniferous period 56-57, 66-67
  Reptiles 80
Carbon ink stick 444
Carbonized wood 430
Carbon monoxide
  Mars' atmosphere 43
  Venus' atmosphere 37
Carbon powder 311
Carbon-rich earth layers 66
Car-building robots 609
Carburetor
  ARV light aircraft 425
  Mid West twin-rotor engine 411
  Pegasus Quasar ultralight 427
  Two-stroke engine 366
Carburetor cover 369
Carburetor hot-air intake pipe 422
Carburetor hot air lever 425
Cardiac notch 248

Cardiac region of stomach 179
Cardiac stomach 174
Cardiac vein 250
Carduus tenuiflorus 129
Cargo-carrying boat
Dhow 376
Junk 376
Liberty ship 392
Roman corbita 372-373
Tea clipper 392
Cargo derrick 392
Cargo hatch 376
Cargo hold 372, 392
Car, hybrid 354
Caribbean plate 59
Caribbean Sea 264
Carina 21
Carinal canal 120
Carina plate 173
Carling 380
Carmel formation 276
Carnallite 271
Carnassial teeth 194
Carnivores 104, 194-195
Jurassic period 70
Theropod 84
Triassic period 68
Carnivorous plants 160-161
Pitcher plant 113
Carotid canal 220
Carp 180
Carpals
Bird 189
Bird's wing 191
Domestic cat 195
Elephant 201
Frog 183
Hare 197
Horse 199
Kangaroo 206
Lizard 184
Platypus 206
Rhesus monkey 202
Seal 204
Carp angling 562
Carpathian mountains 77, 265
Carpels 140-141
Dehiscent fruit 151
Fertilization 146-147
Fruit development 148-149
Insect-pollinated plant 144
Lemon fruit 148
Ovary 140
Stigma 140
Style 140
Carpel wall 148, 151
Carpophore 151
Carpus
Crab 172
Crayfish 173
Human 218
Carrara white marble 453
Carriage 413, 570
Carriage drivebelt 574
Carriage shaft 571
Carrick bend 387, 389
Carrion crow 193
Carrot 128, 132
Carrying fork 334
Carrying wheel 324
Cartilage
Auricle 242
Bony fish 180
Meatus 242
Wrist 230
Cartilaginous fish 178-179, 180
Cartouche 458
Cartridge starter 408
Caruncle 213
Carved sculpture 452, 453
Carved stone 488
Carvel-built hull 376, 391
Carvel planking 376, 377
Carving
Asian building 490-491
Gothic building 470
Sculpture 452
Carving mallet 452
Caryopses 113, 150
Casa de las Conchas 476
Casa del Fascio 495
Caspian Sea 265
Cassette compartment lid 582
Cassini Division 46, 47
Cassini space probe 614
Cassiopeia 19
Cassowaries 188
Cast alloy wheel 346
Cast aluminum wheel spider 336
Castanea sativa 136, 150
Castanets 504, 517
Casting 452, 454
Cast-iron 492-493
Cast-iron chair 331
Cast iron cylinder barrel 363
Castle-deck gunport 376-377
Castles, 374, 466-467
Castor 18, 21
Castor canadensis 197
Cat 104, 194-195
Catalyst 355
Catalytic converter 344, 350, 356
Catamaran 560
Cataphoresic coating 348
Cataphyll 152
Cat block 381
Catcher's mask 536
Catch glove 550
Catena 372
Catenary 328, 330
Caterpillar 168, 169, 611
Eggs 192
Catharina 40
Cathead
74-gun ship 380
Battleship 395
Cathedral of St. Lazare 468
Cations 308
Catkin 144
Catted anchor 381
Cattle 104, 198
Caucasus 265
Caudal fin 178, 179, 180-181
Caudal musculature 90, 95
Caudal plate 92-93
Caudal spike 92-93
Caudal vertebrae
Ankylosaurus 95
Archaeopteryx 85
Crocodile 186
Diplodocus 90
Domestic cat 195
Elephant 201
Eryops 81
Euoplocephalus 95
Gallimimus 86
Hare 197
Horse 199
Iguanodon 96, 97
Kangaroo 206
Kentrosaurus 93
Lizard 184-185
Parasaurolophus 98
Plateosaurus 89
Platypus 206
Rhesus monkey 202
Seal 204
Stegoceras 101
Stegosaurus 93
Struthiomimus 87
Triceratops 102
Tuojiangosaurus 93
Tyrannosaurus 84-85
Westlothiana 81
Caudate nucleus 237
Caudex 113
Caudo-femoral muscle 97
Cauliculus 460
Caulophryne jordani 180
Cave bear skull 77
Caves 284-285
Coastline 294-295
Glacier 286
Cavetto molding
Ancient Egyptian building 458-459
Baroque church 479
French temple 485
Gothic building 472
Renaissance building 477
Cavies 196
Cayley, Sir George 398
CCD (Charge-Coupled Devices) 570
C clef 502
CD/DVD drive 567
Cedar-tree laccolith 274
Ceilings 463, 484
Celestial equator
Stars of northern skies 18-19
Stars of southern skies 20-21
Celestial poles 18
Celestial sphere 18
Cell
Alga 116-117
Body 217
Building 469, 485
Chusan palm leaf 130
Clubmoss stem 120
Collar 166
Dicotyledon 126-127
Epidermal 166
Epiphytic orchid 162
Fern rachis 121
Horsetail stem 120
Leaf 126, 139
Marram grass 113
Monocotyledon 126-127
Moss 119
Mushroom 115
Photosynthesis 138-139
Pine 124-125
Pore 166
Root 132-133
Root tip 152
Sinus 112
Spirogyra sp. 117
Stem 134-135
Wetland plants 158-159
Cella 461, 463, 485
Cell body 239
Cell membrane 217
Cell nuclear membrane 216
Cell nucleus 217
Cell nucleus residue 234
Cello 503-505, 510
Cellphones 588-589
Cells 607
Cellulose fiber insulation 602
Cell wall
Alga 112, 116
Leaf 139
Palisade mesophyll 139
Root 132
Spirogyra sp. 117
Stem surface 156
Celsius temperature scale 590
Cement-based adhesive 450
Cement gland 173
Cement-rendered wall 494
Cenozoic era 57, 74, 76
Fossil record 279
Censer 488
Centaurium erythraea 144
Centaurus 18, 21
Centaurus A (radio galaxy) 13
Centaurus and Crux 21
Central Asia 64
Central bulge 12, 14
Central canal 238
Central computer control 328
Central deflector 612
Central electrode 306
Central nervous system 238
Central peak
Degas and Brönte 34
Venus' craters 36
Central retinal artery 240
Central retinal vein 240
Central shield 187
Central sulcus 236-237
Center
Australian football 528
Basketball 532
Canadian football 526
Football 526
Lacrosse 541
Netball 535
Rugby 530
Centerboard 561
Center buckeye coupler 326
Center circle
Australian rules football 528
Basketball 532
Ice hockey 550
Netball 535
Soccer 524
Center console 353
Center court 545
Centered rudder 375
Center element 599
Center field 536
Center flag 529
Center forward 540
Center gangway 329
Center Georges Pompidou 496-497
Center girder 393
Center half 540
Center halfback 528, 529
Center half-forward 528, 529
Center line 413, 415
Fencing piste 557
Ice hockey 550
Soccer 524
Center-line beam 426-427
Center line keelson 393
Centrifugal brake 562
Centrifugal compressor 418
Centrifugal effect 297
Centriole 217
Centripetal river drainage 288
Centrum 187
Cephalapsis 65
Cephalic groove 173
Cephalic vein
Human 253
Octopus 176
Cephalopods 176, 279
Cephalothorax
Crayfish 173
Malacostraca 172
Scorpion 170
Shrimp 172
Spider 170-171
Cepheus 19
Ceramic end-piece 319
Ceratopsia 83, 103
Ceratosauria 83
Ceraunius Tholus 43
Cercidyphyllum sp. 72
Cerebellum 212, 236-237, 238
Cerebral areas 237
Cerebral ganglion 169, 177
Cerebral vessel 237
Cerebrum 212, 236-237, 238
Cereoid cactus 129
Cerium 310
Ceropegia woodii 157
Ceruchi 372
Cerussite 269
Cervical musculature
Euoplocephalus 94
Gallimimus 86
Cervical nerves 238
Cervical plate 92-93
Cervical rib 84, 96, 100-101, 103
Cervical vertebrae
Archaeopteryx 85
Arsinoitherium 104
Bird 189
Brachiosaurus 91
Crocodile 186
Domestic cat 195
Elephant 201
Eryops 80
Hare 197
Horse 199
Human 212, 222, 245
Iguanodon 96
Kangaroo 206
Kentrosaurus 93
Lizard 184
Parasaurolophus 99
Plateosaurus 88
Platypus 206
Rhesus monkey 202
Seal 204
Stegoceras 101
Stegosaurus 93
Struthiomimus 87
Toxodon 106
Tuojiangosaurus 93
Tyrannosaurus 84
Cervix 258-259
Cervus elephas 199
Cesium 310
Cetaceans 204-205
Cetiosaurus 91
Cetorhinus maximus 179
Cetus 19, 20
Chaffinch 193
Chain
Bicycle 358-359, 360-361
Drum kit 518
Wheel and axle 320
Wooden sailing ship 378
Chain bobstay 382
Chain drive
Motorcycle clutch 362
Werner motorcycle 366
Wright Flyer 398-399
Chain locker 393
Chain motif 491
Chain plate 382
Chain swivel 386
Chain wale 376-377
Chajya 489
Chalcedony 271
Chalk 430
Tempera 432
Gesso 434
Pastel making 440
Fresco 434
Sedimentary rocks 277
Chamber
Building 465, 491
Gun turret 396
Chambers
Seaweed 116
Stomach 198
Substomatal 139
Chamfered corner 485, 488, 494
Championship golf courses 546
Change 321
Chang Jiang 265
Channel
74-gun ship 381
Sailing warship 376-377
Temple of Neptune 460
Wooden sailing ship 378
Channelled wrack 116
Chapel
Baroque church 479
Gothic church 470
Medieval church 469
Chapel pier 467
Chaplet 454
Chapter-house 472
Charcoal drawing 430-431
Charentais melon 149
Charge
Four-stroke cycle 343
Modern engines 344
Charged atom 306, 308
Charged particle 316
Charging with ball 533
Charon 50
Chart house 394
Chase 395
Chassis
Digital camera 580
First cars 334-335
Ford Model T 338
Kirby BSA sidecar 369
Microwave combination oven 596
Monocoque 363
Motorcycle 362, 364-365
Microsoft Zune HD 587
Oldsmobile chassis 337
Panhard-system
Volkswagen Beetle 340
White Steam Car 342
Chassis earth terminal 597
Chassis electrical plug 357
Chassis frame 338
Chassis number 327
Chataya arch 491
Châteaux 474, 476-477
Chat selector button 576
Chattra 491
Chattravali 490-491
Chauffeur's seat 334
Checkerbloom 136
Check pawl 562
Cheek
74-gun ship 381
Dunkeld wet fly 563
Horse 199
Human 212
Running block 383
Sailmaker's mallet 384
Stegosaurus 92
Cheek horn 103
Cheek-piece
Harness racer 555
Showjumper 554
Cheek pouch 98, 196
Cheek teeth
Ankylosaurs 92
Carnivores 194
Ornithopods 96
Tetralophodon 104
Theropods 84
Cheese 382, 388-389
Cheiracanthus 65
Cheirolepsis 65
Chekhov 35
Chela 170, 172, 173
Chelicera 79
Chelicerae 170-171
Chelicerates 279
Cheliped
Crab 172
Crayfish 173
Chelonia 186
Chemical bond 307
Chemical change 280-281
Chemical energy 314-315
Chemical equations 312

Chemical properties
Electrons 308, 310
Substances 306
Chemical reactions 312-313
Chemical sedimentary rocks 276
Chemical symbols 312, 591
Periodic table 310-311
Chemical weathering 282
Chemise 466-467
Chemistry symbols 621
Cherry 148
Cherry wood 512
Chert 277
Cherub 472
Chervil 135
Chest
Gorilla 203
Human 211, 214
Lion 194
Chestnut 198
Chest padding 551
Chest pass 532, 535
Chest protector 527
Chevet 469
Chevron 81, 85, 87, 89, 93, 95-96, 98, 101-102
Chevron fold 61
Chevron-tread tire 336
Chi1 Orionis 18
Chi2 Orionis 18
Chiastolite hornfels 275
Chihuahuan Desert 264
Chile 331
Chimney
Bordino Steam Carriage 334
"Ellerman Lines" steam locomotive 325
Iron paddlesteamer 393
"Rocket" steam locomotive 324
Chimney-shaft 467
Chimney-stack 476, 483
Chimpanzee 202-203
Chin
Bird 188
Human 211, 212
China
Ball games 524
Late Carboniferous period 66-67
Middle Ordovician period 64-65
Ornithopod 96
Railroad track gauge 331
Thyreophorans 92
Chinese calendar 618
Chinese characters 445
Chinese junk 376
Chinese white 438
Chin groove 199
Chin guard 553
Chin gun turret 408
Chinle formation 276
Chin rest 510-511
Chin spoiler 346
Chipmunk 196
Chirostenotes 87
Chisel 452-453
Chlamydomonas sp. 116
Chlorenchyma 120
Chloride 296
Chlorine 311
Chlorophyll 138
Chloroplast 139
Photosynthesis pigment 116, 138, 162
Chlorophyta 116
Chloroplast 138-139
Alga 112
Chlamydomonas sp. 116
Envelope 139
Epiphytic orchid 162
Internal view 139
Spirogyra sp. 117
Choanocyte 166
Choir 468-469, 470, 472
Choir manual 514
Choir-screen 470
Choir-stall 470
Choir stop 514
Chondrichthyes 178
Chondrostean fish 69
Chong Ch'ol 35
Chordae tendineae 251
Chorioallantoic membrane 192
Chorion 260
Choroid 240
Christian architecture 468
Christmas rose 139
Chromate ion 312
Chrome passivation 348
Chrome plating 347
Chrome trim strip 341
Chromium
Mineralization zones 281
Oxide 312
Periodic table 310
Chromosphere 32-33
Chrysalis 168
Chrysanthemum morifolium 129
Chryse Planitia 43
Chrysler Building 495
Chrysocyon brachyurus 195
Chuck 601
Chuck key 601
Chung-ta-wei 376
Church
Santa Sophia 487
Sorbonne 486
St. Botolph 473
St. Eustache 477
St. George in the East 478, 481
St. Maclou 470, 472
St. Maria della Salute 478
St. Maria della Vittoria 478
St. Paul-St. Louis 478-479
St. Pierre de Libreville 496, 499
St. Serge 469
Church-roof boss 468
Chusan palm 127, 130
Ciconia ciconia 188
Cigarette lighter adapter and speaker cable 590
Ciliary body 241
Cincture 477
Cinder 272
Cinder cone
Igneous rock structures 274
Volcanic structure 273
Cinema, home 584-585
Cinnabar 271
Cinquefoil molding 471
Circle 479, 622
Circle area measurement 590
Circle pad 579
Circuit 316
Circuit board 579, 582, 585, 589
Circuit board plug 596
Circuit breaker 314
Circular mountain lake 293
Circulatory system 252-253
Circumference 622
Cirque 286-287
Cirque formation 287
Cirque Napoleon 478-479
Cirri 172
Cirrocumulus cloud 302
Cirrostratus cloud 302
Cirrus 173
Cirrus cloud
Neptune 50
Structure of Mars 43
Weather 302-303
Citrus limon 148
City bus 332
Civet 194
Cladding 494, 496, 498-499
Cladode 129
Cladonia floerkeana 114
Cladonia portentosa 114
Clam 176
Clamp
Cross-stave 377
Intaglio printing 313
U-tube 446
Clarinet 503-504, 508
Classical-style architecture 474, 478, 482
Clastic sedimentary rocks 276
Claves 517
Clavicle
Bird 189
Bony fish 181
Eryops 80
Human 211, 218
Kangaroo 206
Rhesus monkey 202
Clavius 40
Clavus 373
Claw
Albertosaurus 84
Anchisaurus 89
Archaeopteryx 85
Beetle 168
Bird 188
Bumblebee 168
Caiman 187
Chick 193
Crab 172
Crayfish 173
Dinosaur 83
Herrerasaurus 86
Kangaroo 207
Lizard 184
Marble sculpture 452
Pachycephalosaurus 100
Psittacosaurus 103
Scorpion 170
Spider 171
Stegoceras 101
Terrapin 187
Tyrannosaurus 84
Clawed feet 190, 206
Clay 298
Clay daub 465
Clay modeling 452, 455
Clay mounds 286
Clear space 534
Cleavage 270
Clef 502
Cleithrolepis granulatus 69
Cleithrum 80
Clematis 130-131, 137
Clench nail 375
Cleomedes 40
Cleopatra Patera 37
Clerestory 459, 472, 479
Clew 373
Clewline 379, 385
Cliffs
Coastlines 294-295
River's stages 289
Sedimentary rocks 276-277
Climate
Carboniferous period 66
Geological time 56
Oceans and seas 296
Weather 302
Climatic change
Coastline 294
Geological time 56
Clincher wheel 339
Clinker-built hull 375
Clinker-built oak planking 375
Clints 284-285
Clitoris 258
Cloaca
Bird 189
Brachiosaurus 90
Dogfish 179
Euoplocephalus 95
Frog 182
87
Lizard 185
Spider 170
Tortoise 187
Cloacal opening 185
Clock operator 532
Clock tower 493
Cloister 472
Cloning technology 606-607
Close-stowing anchor 386
Cloud deck 50-51
Cloud features
Neptune 50
Saturn 46
Venus 36
Clouds
Earth's atmosphere 301
Jupiter 44-45
Mars 42-43
Neptune 50-51
Saturn 46-47
Uranus 48-49
Venus 36-37
Water cycle 288
Weather 302-303
Cloud shadow 50
Clouds of dust and gas
Life of massive star 24
Milky Way 14-15
Nebulae and star clusters 16-17
Origin and expansion of universe 11
Small stars 24
Cloudtop temperature
Structure of Jupiter 45
Structure of Neptune 51
Structure of Saturn 47
Structure of Uranus 49
Clove hitch 388
Cloven hoof 198
Clubmosses 64, 66, 120-121
Clump cathead 395
Clustered column 469
Clutch 364, 366
Clutch and flywheel 340
Clutch cable 350, 363, 365
Clutch center plate 351
Clutch cover 363
Clutch lever 363, 369
Clutch pedal 350
Clutch pressure plate 351
Clutch release bearing 351
Clypeaster 279
Cnidocytes 166-167
CNS 258
Coal
Earth's evolution 57
Mineral resources 280-281
Power stations 314
Sedimentary rocks 276
Steam locomotive 324
Coal-forming forests 57
Coal measures 61
Coaming 381
Coastal spring 292
Coaster 374-375
Coastlines 294-295
Cave 284
Cobalt
Mineralization zones 281
Periodic table 311
Cobra lily 160-161
Coccosteus 65
Coccygeal cornu 223
Coccygeal vertebrae 222
Coccyx 218, 222
Cochlea 242-243
Cocking lever 549
Cockpit
Airbus 380 573
Avro biplane 403
Kayak 560
LVG CVI fighter 405
Modern military aircraft 420-421
Sailing dinghy 561
Schleicher glider 426
Cockpit canopy 409
Cockpit coaming 425
Cocoa 148
Coconino sandstone 276
Cocos nucifera 135
Cocos plate 59
Cod 180
Codiaeum variegatum 136
Coelenterata 166
Coeliac trunk 256-257
Coelodonta 76-77, 104
Coelophysidae 69
Coelurus 87
Coenobium 116
Coffer 463, 485
Coffered vault 485
Coffering 475
Cogged drive belt 344
Coil spring
"Ellerman Lines" steam locomotive 324
Motorcycle 364
Coil suspension spring
"Deltic" diesel-electric locomotive 327
"Eurostar" multi-voltage electric train 329
Wagon bogie 331
Coke hopper 334
Cold air intake 420
Cold-air unit 417
Cold front 302-303
Cold occlusion 302
Cold-water pipe 405
Cold-water upwelling 296
Coleoptera 168
Coleus sp. 134
Collagen and elastic fibers 252
Collapsed crater 293
Collar
Cathedral of Notre Dame de Paris 473
Sea anemone 167
Snail 177
Collar-beam 473
Collar bone 211, 218
Collar cell 166
Collar of horsetail 120
Collecting duct 256
Collecting tubule 256
Collective lever 422
Collenchyma 126, 134-135
Colliding plates 272
Colloids 306
Colon
Butterfly 169
Cow 198
Human 215, 249, 259
Rabbit 196
Colonette
Gothic church 473
Islamic building 488
Medieval building 467-469
Neoclassical building 479
Renaissance building 474
Colonnade
Ancient Greek building 460-461
Ancient Roman building 462-463
Cathedral dome 484, 487
Neoclassical building 483
Colonnaded story 494
Color 270
Color changes 312-313
Color ink cartridge 574
Color ink-cartridge clamp 574
Color light signals 330
Color wheel 439
Colorado River
Earth's evolution 57
Grand Canyon 277
Valley 277
Colosseum 462, 464-465
Colpus 144
Columba 18, 21
Columella 119, 145
Column
Ancient Egyptian building 458-459
Ancient Greek building 458, 460
Ancient Roman building 458, 462-463, 465
Baroque church 480-481
Cathedral dome 487
Cave system 285
French temple 485
Gothic church 473
Islamic mosque 488
Medieval church 468-469
Modern building 496-498
Monocotyledonous flower 126
Neoclassical building 478-479, 483
Nineteenth-century building 492-493
Renaissance building 477
Coma 52-53
Coma Berenices 18, 21
Combat sports 556-557
Combination lever 325
Combustion 326
Combustion chamber
Capacity 366-367
Iron paddlesteamer 393
Jaguar straight six engine 344
Jet engines 418-419
Combustion cycle 410
Comets 30, 52-53
Common bile duct 252
Common blackheaded gull 189
Common brittle star 175
Common carotid artery 215, 251, 253
Common centaury 144
Common crus 245
Common digital extensor muscle 84, 97
Common elder 143
Common English ivy 131
Common horse chestnut 130
Common horsetail 120
Common Iguana 82
Common iliac artery 215, 253, 257
Common iliac vein 215, 253, 257
Common ivy 137
Common lime 143
Common link 386
Common mulberry 130
Common peroneal nerve 238
Common rafter 473, 486

Common starfish 175
Common tern 193
Common time 502
Communication 108
Communications aerial 424
Commutator 600
Commuters 363
Compact bone 224-225
Compact disc 584, 586
Companion cells 132-134
Companion ladder 381
Companion way 380
Company logo 572
Compass
  Battleship 394
  Vault decoration 485
Compass and rangefinder platform 394
Competent bed rock 61
Competition motorcycles 368-369
Competitions
  Archery 548
  Diving 558
  Judo 556
  Rowing 560
  Skiing 552-553
Complete mesentery 167
Composite capital 478
Composite column 478
Composite pilaster 478
Composite volcano 272
Composter 602
Compound eye
  Beetle 168
  Bumblebee 168
  Butterfly 169
  Crab 172
  Crayfish 173
  Damselfly 168
  Malacostraca 172
  Shrimp 172
Compound inflorescence 131, 142
Compound leaf 130-131, 136
Compound pier 468-469
Compound pulleys 320
Compounds 268, 306, 308
Compound succulent fruit 148-149
Compound umbel 143
Compressible gas 365
Compression
  Faults and folds 60
  Glacier 286
  Igneous and metamorphic rocks 274
  Mineral resources 280
  Mountain building 62
  Rock cycle 266
Compression ring
  Ford diesel engine 347
  Jaguar straight six engine 344
Compression stroke 343
Compressor 418
Compressor piston 344
Compsognathus 70
Computer
  and Email program 677
  Electronic instruments 520
  Laptop 567
  Modern bodywork 348
  Tablet 568-569
Computerized ignition system 344
Concave brace 477
Concave molding 482
Concave wall 478, 481
Concealed lighting 572
Conceptacles 116-117
Concert grand piano 515
Concha
  Ear 242
  Nasal 221, 241
Conchoidal fracture
  Extrusive igneous rocks 275
  Fracture 270
  Sedimentary rocks 277
Concorde 416-417
Concrete 492, 494, 496-499
Concrete shielding 314
Concrete shoe 499
Concrete track 328
Concrete wall 463, 465, 496
Condensation 307
  Nuclear power station 314
  Testing candle wax 313
Condensation level 302
Condenser 342
Condenser aperture 610
Condenser housing 611
Condenser lens 611
Conducting tissue 119
Conductor
  Electrical circuit 316
  Generating magnetism 317
  Orchestra 504
Conductor's stand 505
Condylaictis sp. 166
Condyle
  Carnivore 194
  Human 220
Cone 623
Cones
  Bishop pine 124
  Gymnosperms 122
  Igneous and metamorphic rocks 274
  Pine 122
  Scots pine 122
  Smooth cypress 123
  Volcanoes 272-273
  Welwitschia 123
  Yew 123
Cone sheet 274
Cone stalk 124
Cone surface area measurement 590
Cone volume measurement 590
Congas 519
Congo Basin 39
Congo River 265
Conical bore 507
Conical dome 476
Conical map projection 265
Conical spire 466, 476
Conical volcano 272
Conifer
  Cretaceous period 72
  Earth's evolution 57
  Fossil record 279
  Gymnosperm 122-125
  Jurassic period 70
  Triassic period 68
Coniferophyta 122
Conjugation 117
Conjunctiva 241
Connecting rod
  Bordino Steam Carriage 334
  Flat-four cylinder arrangement 340
  Four-stroke cycle 343
  Iron paddlesteamer 392
  Jaguar straight six engine 344
  Jaguar V12 engine 345
  Mid West two-stroke engine 410
  Steamboat with paddle wheels 391
Connecting wire 598
Connective tissue cells
Connectors 569
Conning tower 394, 397
Conocephalum conicum 118
Con-rod 340, 343-345
Conservation of Energy Law 314
Conservatory 602, 603
Console 579
Constellations 18-21, 613
Constratum 373
Constrictor snakes 184
Construction sculpture 452
Contact 352
Contact grid 605
Contact metamorphism 274
Contant d'lvry 478
Contest area 556
Contests
  Head-butting 100
  Shooting 548
Continental crust 58-59
  Mineralization zones 281
  Mountain building 62-63
  Ocean floor 298
Continental drift 58
Continental margin sediments 299
Continental rise 298
Continental Sea 73, 75
Continental shelf
  Ocean floor 298
  Prehistoric Earth 69, 71
  Rock cycle 267
Continental slope
  Ocean floor 298
  Offshore currents 296
  Rock cycle stages 267
Continents
  Formation of the Earth 38, 56
  Earth's physical features 264-265
  Geological time 56
Contrabassoon 504-505
Contractile vacuole 116
Control cabinet 396
Control circuit 328
Control buttons 585
Control column
  ARV light aircraft 425
  BE 2B bomber 404
  Curtiss biplane 398-399
Control-column aperture 425
Control flag 552
Controller 332
Control line 561
Control panel 571, 595, 596
Control panel and disc tray cover 584
Control panel boards 597
Control panel fascia 597
Control panel microchips 596
Control panels 594
Control panel wiring 595
Control platform 390
Control reservoir drain 326
Control rod 314, 424
Control room 397
Control stalk 353
Convection cell 33
Convection current 38
Convective zone 24, 33
Converging plates 63
Conversion 530
Convex portico 483
Cook/grill tray 596
Cooking 108
Cooksonia 56
Cooksonia hemispherica 64
Coolant 314
Coolant inlet 424
Coolant jacket 410-411
Coolant outlet
  ARV light aircraft 424
  Jaguar V12 engine 345
  Mid West two-stroke engine 410
Coolant passage 346
Coolant pipe 554
Coolant pump 410
Coolant rail 345
Cooling device 611
Cooling fan 345, 567
Cooling fin
  Drum brake 365
  Mid West rotary engine 411
  Two-stroke engine 366
  Velocette OHV engine 367
Cooling intake 534
Cooling perforations 597
Cooling tank 335
Cooling tower
  Center Georges Pompidou 496-497
  Nuclear power station 314
Cooling water tank 335
Co-orbital moons 46
Coping-stone 495
Copper
  Mineral resources 280-281
  Minerals 268
  Periodic table 311-312
Copper body-shell 519
Copper face 384
Copper nitrate solution 312
Copper ore 306
Copper plate nib 444
Copper sheathing 392
Copper sulfate 313
Coprates Chasma 43
Copulatory bursa
  Butterfly 169
  Snail 177
Coracoid
  Bird 189
  Diplodocus 90
  Euoplocephalus 94
  Gallimimus 86
  Triceratops 102
  Turtle 187
  Tyrannosaurus 84
Coral 78, 166-167
  Atoll development 299
  Fossil record 279
Corallina officinalis 117
Coral reef
  Earth's evolution 56
  Ocean floor 298
Cor Anglais 504-505, 508
Corbel
  Cathedral dome 487
  Medieval building 467, 469
  Neoclassical building 482
  Nineteenth-century building 493
  Renaissance building 477
  Rococo style 478
Corbita 372-373
Cor Caroli 18, 21
Cordaites 67
Cordate leaf bases 136-137
Cordite case 396
Cordite handling room 396
Cordite supply shuttle 396
Core
  Earth 38-39
  Helix Nebula 17
  Massive stars 26-27
  Moon 40
  Neutron stars and black holes 28-29
  Small stars 24-25
  Structure of comet 53
  Structure of Earth 63
  Structure of Jupiter 45
  Structure of Mars 43
  Structure of Mercury 35
  Structure of Neptune 51
  Structure of Pluto 51
  Structure of Saturn 47
  Structure of Uranus 49
  Structure of Venus 37
Core-engine jet pipe 412, 415
Core jet pipe 419
Core temperature
  Structure of Earth 39
  Structure of Jupiter 45
  Structure of main sequence star 24
  Structure of red giant 25
  Structure of red supergiant 26
  Structure of Saturn 47
  Structure of Sun 33
  Structure of Uranus 49
Corinthian capital 460, 463, 479, 481
Corinthian column 463-464, 479-480
Corinthian entablature 463
Corinthian order 460, 462
Corinthian pilaster 463-464, 480-481
Coriolis force 296-297, 300
Cork
  Oboe 508
  Stems 134-135
  Woody dicotyledons 127
Corms 154-155
Corn 112
Cornea 241
Corner arc 524
Corner seal 347
Cornet 506
Cornice
  Ancient Egyptian temple 458-459
  Ancient Greek building 460-461
  Ancient Roman building 462-465
  Asian building 491
  Baroque church 479-481
  Dome 484, 486
  French temple 485
  Gothic church 470-473
  Islamic tomb 489
  Medieval building 466-467, 469
  Neoclassical building 478-479, 482-483
  Nineteenth-century building 493
  Renaissance building 474-477
  Twentieth-century building 494
Cornucopia 480
Corolla 140, 142-143
Corona
  Earth's atmosphere 300
  Palazzo Strozzi 475
  Sun's atmosphere 32-33
Corona Australis 19
Corona Borealis 18, 21
Coronal section through brain 236-237
Coronal suture 220
Coronary artery 250-251, 253
Coronary sinus 250
Corona temperature 33
Coronet 198, 554
Coronoid process 194, 220
Corpus albicans 258
Corpus callosum 236-237
Corpus cavernosum 259
Corpus luteum 258
Corpus spongiosum 259
Corridor 465
Corries 286-287
Corrugator supercilii muscle 228-229
Cortex
  Apical meristem 134
  Canadian pond weed 158-159
  Clubmoss stem 120
  Dicotyledon 127
  Epiphytic orchid 162
  Hair 234
  Horsetail stem 120
  Kidney 256
  Lichen 114
  Monocotyledon 127
  Moss 119
  Pine 125
  Radicle 152
  Rhizome 155
  Root 132-133
  Stems 134-135
  Water hyacinth 158
  Water lily 159
Corundum 271
Corvus 18, 21
Corvus corone 193
Corynactis viridis 166
Corythosaurus 96, 98
Cosmic background radiation 10
Cosmic ray 301
Costal cartilage 218
Costal facet 223
Costal margin 168, 169
Costal shield 187
Cotter pin 383
Cotton duck canvas 437, 443
Cotyledon 126, 152-153
  Development 132
  Dicotyledon 126
  Dry fruit seed 150-151
  Embryo development 147
  Epigeal germination 153
  Hypogeal germination 152
  Monocotyledon 126
  Pine 122
  Root development 132
  Seed 152-153
  Succulent fruit seed 148-149
Couch grass 113
Coucy-le-Chateau 466-467
Coulomb 316
Counter
  Calligraphy lettering 445
Counterbalancing weight 506
Counter, galley 573
Counter rail 381
Counter timber 381
Counterweight
  Flat-four cylinder arrangement 340
  Four-stroke cycle 343
  Hong Kong and Shanghai Bank 498
  Jaguar V12 engine 345
  Output shaft 347
  Relief printing press 449
  Rotary engine output shaft 410
  Trojan engine 342
  V12 cylinder arrangement 345
Country code 576
Coupling
  Conventional hookscrew 328
  "Ellerman Lines" steam locomotive 324
Coupling rod 325

Couronnement 472
Course
  Asian building 491
  Medieval building 466-467
  Neoclassical building 483
  Nineteenth-century building 492-493
Court referee 535
Court
  Basketball 532
  Handball 535
  Netball 535
  Volleyball 534
Court seal 375
Courtship display 188
Courtyard 465, 466
Coussinet 460
Covalent bonding 308-309
Cove 381
Coved dome 478, 485
Cover point 541
Cover support 570
Coverts 188, 191
Cow 198
Cowhide face 384
Cowling fastener 408
Cowling panel 407, 412
Coxa
  Beetle 168
  Crayfish 173
  Scorpion 170
Coxswain 560
CQR anchor 386
Crab 172
Crab apple 126
Crab cactus 129
Crab Nebula 28
Cracks 284-285
Cradle frame
  Honda VF750 364
  Weslake Speedway motorcycle 369
Cradling 541
Crane 498
Cranial nerves 238
Cranium
  Ankylosaurus 94
  Archaeopteryx 85
  Australopithecus 108
  Bat 105
  Camarasaurus 91
  Diplodocus 90
  Elephant 201
  Eryops 80
  Euoplocephalus 94
  Homo sapiens 108
  Hyaenodon 107
  Iguanodon 96
  Kentrosaurus 93
  Lambeosaurus 99
  Moeritherium 105
  Opossum 106
  Pachycephalosaurus 100
  Panoplosaurus 94
  Parasaurolophus 99
  Plateosaurus 88
  Prenocephale 100
  Protoceratops 102
  Stegoceras 100
  Stegosaurus 93
  Struthiomimus 87
  Styracosaurus 102
  Toxodon 106
  Triceratops 103
  Tuojiangosaurus 93
  Tyrannosaurus 84
Crank 320
  Brace-and-bit 601
  Eddy Merckx racing bicycle 360
  "Ellerman Lines" steam locomotive 325
Crank bolt 358, 360
Crankcase
BE 2B bomber 404
  British Rail Class 20 diesel engine 327
  Humber engine 343
  Jaguar straight six engine 344
  Jaguar V12 engine 345
  Mid West two-stroke engine 410
  Oldsmobile engine 336
  Trojan engine 342
  Velocette OHV engine 367
  Werner motorcycle 362
Crankcase breather pipe 402
Crank handle 339
Crankpin 343
Crankshaft
  Benz Motorwagen 335
  Flat-four cylinder arrangement 340
  Four-stroke cycle 343
  Iron paddlesteamer 392
  Mid West two-stroke engine 410
  Oklsmobile engine 336
  Oscillating steam engine 391
  Straight four cylinder arrangement 345
  Two-stroke engine 366
  Velocette OHV engine 367
Crankshaft counterweight 344
Crankshaft pulley 344, 355
Crash bar 362-363
Crash cymbal 518
Crash helmet 552
Crater
  Mercury's North Pole 35
  Northern stars 18
  Oceanus Procellarum 40
  Southern stars 21
  Surface features of Mars 42
Crayfish 172-173
Crayon 448
Creative Zen Stone 586
Creeping stems 154
  Clubmoss 120
  Strawberry 128
Cremasteric fascia 259
Cremocarp 150-151
Crenellation 466
Crepidoma 461, 481
Crescent-shaped dune 283
Crest
  Building 479, 488, 493
  Fold formation 60
  Horse 199
  Lizard 184
  Ship's shield 395
Crested porcupine 197
Cretaceous period 72-73
  Fossil record 279
  Geological time 56-57
Crevasse 287
Crevice 284
Crevice tool 593
Crew handrail 612, 613
Crew's seat 416
Cricket (animal) 168
Cricket (game) 538-539
Cricoid cartilage 255
Cricothyroid ligament 244
Cricothyroid muscle 229, 244-245
C ring 46-47
Cringle 384
Crista 242
Crocket 471-472
Crocodile clip connector 316
Crocodiles 68, 73, 186-187
Crocodylus niloticus 186
Crocoite 271
Cronaca 474
Crook 508
Crop
  Bird 189
  Butterfly 169
  Octopus 176
  Snail 177
Crop-duster 410
Crops 315
Crop-sprayer 410, 422
Cross
  Baroque church 480
  Dome 486-487
  Motif 472
Crossandra nilotica 145
Crossbar
  Calligraphy characters 445
  Eddy Merckx racing bicycle 360
  Gaelic football 529
  Handball 535
  Hurling 540
  Rugby 530
Cross-bed set 283
Crossbow 548
Cross-bracing 497-499
Cross-country skiing 548
Crosse 540-541
Crossing 469-470, 477
Crossing tower 468
Cross-member 338-339
Cross-piece 376-377, 387
Cross-pollination 144
Cross-staff 377
Cross-stave 376-377
Cross tube 423
Cross wall of hypha 115
Crosswise strut 512
Crotchet rest 502-503
Croton 136
Crouch 543
Croup 198
Crow 193
Crown
  Bird 188
  Building 484, 490
  Danforth anchor 386
  Harp 511
  Head 212
  Relief-printing press 449
  Rigging 382-383
  Roman anchor 372
  Sail hook 384
  Shackle 386
  Teeth 247
  Timpanum 519
Crowning cornice
  Ancient Roman building 464, 465
  Baroque church 479
  Renaissance building 474-475
Crown wheel
  Benz Motorwagen 335
  Ford Model T 338
Cruciform column 492
Cruciform pedestal 481, 487
Cruck frame 466
Cruise electronics module 615
Cruise stage 615
Crumb tray 598-599
Crupper 555
Crusafontia 56
Crus cerebri of midbrain 237
Crus of diaphragm 255
Crust
  Moon 41
  Ocean floor 298
  Pulsar 28
  Regional metamorphism 274
  Structure of comet 53
  Structure of Earth 38-39
  Structure of Mars 43
  Structure of Mercury 35
  Structure of Venus 37
Crustaceans 172-173
  Arthropoda 170
  Cretaceous period 72-73
  Fossil 279
Crustal movement
  Coastline 294
  Faults and folds 60
  Mineralization zones 280
  Mountain building 62
  Rock cycle 266
  Volcano 272
Crustal plate boundary 39
Crustal plates 58-59, 60
Crustose lichen 114
Crutch
  Viking karv 375
Crux-Centaurus Arm 14
Crypt 467
Crypt-window 481
Crystalline external crust 28
Crystalline stalagmitic floor 284
Crystallization 307
Crystal Palace Exhibition Hall 492-493
Crystals
  Faults 60
  Intrusive igneous rocks 275
  Mineral features 270-271
  Minerals 268-269
  Solids 307
Crystal systems 270
Ctenidium 176
CT scan 214
Cube 623
Cubic crystal 270
Cubic system 270
Cubital fossa 211
Cuboid bone 232
Cucumis melo 149
Cud 198
Cuesta 283
Culm 131
Cumulonimbus cloud 302
Cumulus cloud 302
Cuneate leaf base 136-137
Cuneus 465
Cup 509
Cup mute 507
Cupola 466, 479, 493
Cupressus glabra 123
Cup-shaped mouthpiece 506-507
Cup surrounding stomata 157
Cupula 242
Cupule 150
Curium 311
Current 296-297
Current electricity 316
Cursor control device (CCD) 573
Curtain 477, 497
Curtain wall 466, 496, 498
Curtiss, Glenn 398
Curtiss Model-D Pusher 398-399
Curved buttress 478-481
Curved cornice 462
Curvilinear tracery 470, 472
Cuscuta europaea 163
Cushion
  Doric capital 460
  Rowing positions 373
Cushion star 175
Cusp
  Asian building 488
  Gothic building 472-473
  Structure of a tooth 247
Cuspate fold 61
Cuspate foreland 294
Cusped arch 489
Cuspidate leaf apex 137
Cutaneous nerve 238
Cuticle
  Bishop pine needle 124
  Dryland plants 156
  Golden barrel cactus 156
  Hair 234
  Haworthia truncata 157
  Leaf 139
  Lithops brom fieldii 157
  Marram grass 113
  Monocotyledon leaf 126
  Nail 231
  Rose stem 135
  Rush stem 135
  Wetland plants 158
Cuttlefish 176
Cutty Sark 392
Cyanotrichite 269
Cycadophyta 122
Cycads 68, 122-123, 279
Cycas revoluta 68, 123
Cycas sp. 68
Cyclic-pitch lever 422-423
Cyclone assembly 592
Cyclonic storm
  Structure of Earth 39
  Structure of Mars 43
  Structure of Neptune 50
Cyclostomata 178
Cygnus 19, 20
Cylinder
  Diesel train 326
  Early engines 342-343
  "Ellerman Lines" steam locomotive 325
  Iron paddlesteamer 392
  Modern piston aero-engines 410
  Motorcycle 362, 366
  Oldsmobile engine 336
  "Rocket" steam locomotive 324
Cylinder barrel
  Mid West two-stroke engine 410
  Werner motorcycle 362
Cylinder block 339
Cylinder-cooling gills 407
Cylinder drain cock lever 325
Cylinder head
  72° V10 engine 356
  ARV light aircraft 425
  British Rail Class 20 diesel engine 327
  Daimler engine 343
  Jaguar straight six engine 344
  Jaguar V12 engine 345
  Mid West two-stroke engine 410
  Oldsmobile engine 336
  Two-stroke engine 366
  Velocette OHV engine 367
Cylinder liner
  Jaguar Straight six engine 344
  Mid West two-stroke engine 410
cylinder shape 623
Cylinder surface area measurement 590
Cylinder volume measurement 590
Cylinder wall 343
Cylindrical fault 61
Cylindrical map projection 264
Cyma recta 475
Cyma reversa 460, 472
Cymatium 475
Cymbals 504-505, 516-517
  Drum kit 518
Cyme 129, 143
Cypress 123
Cypselas 150
Cyrillus 40
Cystic duct 248
Cytoplasm
  Chlamydomonas sp. 116
  Diatom 116
  Human 217
  Palisade mesophyll 139
  Root cell 132
  Thalassiosira sp. 116
Cytosine 216

D

Dacron 548
Dacron sailcloth 384
Dacron skin 426
Dactylus 172-173
Dado
  Baroque church 481
  French temple 485
  Neoclassical building 479
  Renaissance building 476
Dagger 472
Dagoba stupa 490-491
Daimler double-sleeve valve engine 343
Daimler, Gottlieb 334
Daisy gypsum 269
Dakota sandstone 276
D'Alembert 41
Dalmatian coastline 295
Da Maiano, B. 474
Damped anti-shock swivel base 584
Damper
  Piano 514
  TGV electric high-speed train 329
  Wagon bogie 331
Damper bar 516
Damper body 365
Damper pedal
  Concert grand piano 515
  Tubular bells 516
  Upright piano 514
  Vibraphone 517
Damper unit 425
Damp lime-plaster 434
Damselfly 168
Dancette-pattern mosaic 489
Dandelion 150
Danforth anchor 386
Danger area 556
Danilova 36
Dark mica 274
Dark nebulae 16
Darlingtonia californica 160-161
Dart sac 177
Darwin 43
Da Sangallo, G. 474
Dash 353
Dashboard
  1906 Renault 337
  Bordino Steam Carriage 335
  Ford Model T 338
Dashboard radiator 336-337
Dash panel 353
Dash radio speaker 353
Data cartridge 591
Data plug 591
Data plug socket 591
Daucus curola 128, 132
Daughter bulbs 154
Daughter plants 154
Davit 395
D-block 310-311
DC converter 355
DC converter connection 355

DC current 328
DC socket 586
Dead-ball line 530
Deadeye
  74-gun ship 380
  Longboat 380
  Rigging 382-383
  Roman corbita 373
  Sailing warship 377
Deadnettle 135
Dead organisms 278
Dead plant encrustations 284
Dead Sea 292-293
Deadwood 381
Debris
  Glacier 286-287
  Mountain building 62
  Ray crater 34
Decathlon 542
Decidual plate 260
Deciduous plants 130-131
Deciduous teeth 246
Deciduous trees 72
Deck
  Greek trireme 373
  Roman corbita 373
Deck beam
  74-gun ship 380
  Ironclad 393
  Paddle steamer 390, 393
  Roman corbita 372
Deck house 373, 376
Deck lantern 392
Deck planking 393
Deck rail 373
Decorative letter 445
Deep cracks 284-285
Deep current systems 296-297
Deepened valley 295
Deep floor 393
Deep mid wicket 538
Deep-ocean floor 298
Deep-ocean floor sediments 299
Deep peroneal nerve 238
Deep relief carving 453
Deep square leg 538
Deer 104, 198-199
Deer hopper dry fly 563
Defenders
  Ice hockey 550
  Lacrosse 541
  Soccer 524
Defending zones 550
Defense 526, 535
Defensive back 526
Defensive end 526
Defensive tackle 526
Deflation hollow 283
Degreased bare metal 348
Dehiscence 150-151
  Fern spore 121
  Pollen sac 144
Dehiscent fruits 150-151
Dehydration 152
De-icing leading edge 414, 415
Deimos 42
Deinonychus 73
Deinotherium 77
Dekla Tessera 37
de la Cierva, Juan 422
Deleted items folder 576
Delete mail button 576
Delphinium 150
Delphinium orientalis 141
Delphinium sp. 151
Delphinus 19, 20
Delta
  Coastline 294
  River features 290
  River 288-289
  Rock cycle 266-267
Delta Andromedae 19
Delta Crucis 21
Delta formation 291
Delta Hydri 20
Delta II launch vehicle second stage 615
Delta ring 48
Deltavjalia vjatkensis 81
"Deltic" diesel-electric locomotive 326-327
Deltoid leaf 137
Deltoid ligament 232
Deltoid muscle 226-227
Demountable wheel 338-339
Dendrite 239
Dendritic copper 268
Dendritic gold 268
Dendritic river drainage 288
Deneb 19, 20
  Hertzsprung-Russell diagram 23
Deneb Algedi 19, 20
Deneb Kaitos 19, 20
Denebola 18, 21
Dens 222
Density
  Formation of black hole 29
  Massive stars 26-27
  Small stars 24-25
  Stellar black hole 29
Dentary 181
Dentary bone 96, 102, 107
Dentate leaf margin
  Hogweed 129
  Ice-plant 129
  Live-forever 129
  Mulberry 130
  Rock stonecrop 128
Dentil
  Ancient Roman building 462
  Baroque church 479, 481
  Cathedral dome 487
  French temple 485
  Neoclassical building 478
  Renaissance building 475
Dentine 247
Deoxyribonucleic acid strand 139
Deperdussin, Armand 400
Depressed arch
  Ancient Roman building 462
  Islamic building 488-489
Depressions 302
Depressor anguli oris muscle 228-229
Depressor labii inferioris muscle 229
Depth charge 394
Derailleur cage plate 358
Deranged river drainage 288
Dermal armor 95
Dermal papilla 235
Dermis 234-235
Derrick 392, 395
Descender 445
Descending colon 249
Desert 39, 57
  Carboniferous to Permian period 66
  Earth's physical features 264-265
  Rock cycle 266
  Weathering and erosion 282-283
Desertification 57, 76
Desiccated clay 283
Design
  Fresco 434-435
  Modeled sculpture 452
  Mosaic 449
Deslandres 40
Desmid 112
Destination screen 332
Detachable bud 154
Detachable ink reservoir 444
Detachable rim 339
Detector 610
Detergent tray 594, 595
Detergent tray holder 595
Detergent tray recess 595
Deuterium nucleus 22
Deutscher Werkbund style 495
Devonian fish 65
Devonian period 64-65, 80
  Fossil record 279
  Geological time 56
  Primitive life 78
Devon minnow 563
Dewlap 184
Dextral strike-slip fault 61
Dhow 376
Diabase sill 277
Diagonal bracing 401
Diagonal reinforcement 374
Diagonal strut 399
Diagonal turn 388
Dial
  Clocktower 493
  Sundial 377
Diameter 622
  Atoms 308
  Earth 30
  Fluorine-19 atom 309
  Fluorine-19 nucleus 309
  Jupiter 26, 44
  Jupiter's moons 44
  Life of massive star 26-27
  Life of small star 21-26
  Mars 30
  Mars' moons 42
  Mercury 30
  Moon 40
  Neptune 31
  Neptune's moons 50
  Planets 30-31
  Pluto 31
  Saturn 27, 46
  Saturn's moons 46
  Stars 22
  Sun 32
  Uranus 27, 48
  Uranus' moons 48
  Venus 30
Diamond 311
  Mineral features 270-271
  Native elements 268
Diamond-shaped painting knife 436
Diamond whetstone 452
Diaphragm
  ARV Super 2 424
  Chimpanzee 202
  Domestic cat 195
  Elephant 200
  Human 215, 254-255
  Rabbit 196
Diastema 106
Diatom 116
Diceros bicornis 199
Dichasial cyme 143
Dicksonia antarctica 70, 112-113
Dicloelosia bilobata 65
Dicotyledon 126-127, 141-143
Dicyothyris 278
Didelphis 106
Didelphis virginiana 207
Dielectric sandwich 584
Diesel-electric train 326
Diesel fuel injection 326
Diesel motor compartment 397
Diesel, Rudolph 326
Diesel train 324, 326-327
Differential 356
Differential housing 338
Diffuser 356
Digestive caecum 173, 176
Digestive enzymes 160
Digestive gland
  Snail 177
  Spider 170
Digestive glands/zones
  Butterwort 161
  Monkey cup 161
  Venus fly trap 160
Digestive system
  Cow 198
  Human 248-249
Digit 105
Digital artery 231, 253
Digital camcorder 582-583
Digital camera
  3-D digital camera 581
  Digital camera with interchangeable lens 581
  Digital SLR 581
  Underwater digital camera 581
Digital extensor muscle 94
Digital flexor muscle 84
Digital media slot 567
Digital nerve 231
Digital sampler 520-521
Digital vein 253
Digital video camera 582-583
Digitate leaf 137
Digits
  Bird 189
  Bird's wing 191
  Frog 182
  Kangaroo 207
  Rabbit 196-197
  Rat 196
  Salamander 182
  Seal 204
Dike 274
Dike swarm 274
Dilator muscle 241
Dilsea carnosa 117
Dimetrodon loomisi 67
Dinghy 560
Dinosaur cladogram 83
Dinosaur 56-57, 80, 82-83
  Fossil record 279
Dionaea muscipula 160
Dione 46, 614
Dip 60
Diplodocus 70, 88, 90-91
Dip pen 430
Dipping bed rock 60-61
Dipping lug foresail 385
Diprotodon 76
Dip-slip fault 61
Dipstick 354
Dipstick tube 346, 356
Dipterus valeciennesi 81
Direct current 328
Direct current (DC) inlet 571
Direction bar 414
Direction-finding-aerial fairing 408
Direct method mosaic creation 450
Direct-vision panel
  ARV light aircraft 425
  Bell-47 helicopter 422
Dirt track motorcycle racing 368
Disc brake
  Harley-Davidson FLHS Electra Glide 362-363
  Honda CB750 363
  Honda VF750 364
  Husqvarna Motocross TC610 368
  Lockheed Electra airliner 407
  Motorcycle 364-365
  Suzuki RGV500 368-369
Disc brake calliper 364, 368-369
Disconformity 276
Discovery Rupes 35
Discus 542-543
Disk
  Basal 167
  Crab 166-167
  Liverwort 118
  Pedal 167
  Sea anemone 166-167
  Starfish 174
  Starfish fossil 79
Disk drag 562-563
Disk florets 129, 142, 145
Displacement reactions 312
Display button 585
Display controller chip 581
Display panel
  Blu-ray recorder 584
Display screen 585, 596
Display screen and control circuits 585
Distal convoluted tubule 256-257
Distal end of radius 231
Distal interphalangeal joint 231
Distal phalanx 219, 230, 232
Distal tarsal 183
Distance lines
  Gaelic football 529
  Rugby 530
Distance running 542
Distance signaling 330
Distilled water 444
Distiller 397
Distributary
  River features 290-291
  Rivers 288-289
Distributor
  Hawker Tempest Mark V 408
  Jaguar straight six engine 344
  Jaguar V12 engine 345
  Renault Clio 351
Distributor drive shaft 345
Distributor fixing point 346
Diving 558-559
DNA 139, 216, 606
Dobro resonator 513
Dock 554
Document panel 407
Document table 571
Dodder 163
Dog 104, 194-195
Dogfish 178-179, 192
Dog-leg hole 546
Dog-leg staircase 481
Doline 284-285
Dolomedes fimbriatus 171
Dolphins 204-205
Dolphin striker 382
Domain name 576
Dome 484, 486-487
  Ancient Roman building 462
  Asian building 490-491
  Baroque church 480-481
  French temple 485
  Islamic building 488
  Medieval building 467, 469
  Neoclassical building 478
  Renaissance building 475-477
Domed receptacle 142
Domed roof 489
Domed topdeck 401
Domed turret 493
Dome metalling 486
Dome of the Rock 487
Dome timbering 486
Dome volcano 62, 272
Donjon 466-467
Donkey boiler 392
Donor genetic material 606, 607
Door
  Ancient Egyptian tomb 458-459
  Ancient Roman building 463
  Baroque church 479
  Bell 206 jetliner 423
  Double-decker touring bus 333
  Gatwick Express "People Mover" 328
  MCW Metrobus 332-333
  Microwave combination oven 596
  Neoclassical building 478
  Renaissance theater 477
  Renault Clio 349
  Single-decker bus 333
  TGV electric high-speed train 329
  Washer-dryer 594
Door catch 341
Door catch with safety cut-out 595
Door frame 412
Door glass 348
Door handle 341, 348
Door hinge 612
Door jamb 478
Door key and lock 348
Door lock 596, 602
Door metal cap 595
Door molding 353
Door porthole 595
Door safety cut-out mechanism 596
Door trim panel 353
Doorway 474-475, 479, 481, 495
Door wiring loom 595
Doppler 41
Dorado 21
Doric capital 460
Doric column 460, 464
Doric half-column 464
Doric order 460
Dormancy
  Horse chestnut bud 130
  Seed 152
Dormant volcano 272
Dormer head 493
Dormer window 476, 493, 495
Dorsal abdominal artery 173
Dorsal aorta
  Bony fish 181
  Dogfish 179
  Frog 182
Dorsal blood vessel 169
Dorsal fin
  ARV light aircraft 424
  Bony fish 181
  Concorde, the 416
  Dogfish 179
  Dolphin 205
  Lamprey 178
  World War II aircraft 408-409
Dorsal fin ray 181
Dorsal interosseous muscle 233
Dorsal lobe 158
Dorsal mantle cavily 176
Dorsal margin of shell 176
Dorsal metatarsal artery 253
Dorsal plate 78, 92-93
Dorsal scale 184, 186
Dorsal scute 95

Dorsal spine base 78
Dorsal venous arch 253
Dorsal vertebrae
Archaeopteryx 85
Brachiosaurus 90
Diplodocus 90
Eryops 80
Euoplocephalus 94
Gallimimus 86
Iguanodon 96
kentrosaurus 93
Parasaurolophus 99
Pareiasaur 81
Plateosaurus 88
Stegoceras 101
Stegosaurus 93
Struthiomimus 87
Tuojiangosaurus 93
Tyrannosaurus 84
Dorsum 213
Double-arm pantograph 328
Double bass 503-505, 510, 511
Double bassoon 504-505
Double-decker bus 332-333
Double decomposition reaction 312-313
Double-dipper palette attachment 436
Double-ended hull 375
Double flat 502
Double halyard 373
Double helix 216
Double-planet system
Earth 38
Pluto 50
Double-pyramid crystal 270
Double reed 508
Double rope becket 383
Doubles 544
Double samaras
Dry fruit 150-151
Sycamore 131
Double scull 561
Double sharp 502
Double topsail schooner 385
Dowel
Mid West single rotor engine 410
Mortiee-and-tenon fastening 373
Dowel hole 410-411
Downfolds 60
Downhaul 385
Downhill skiing 552
"Downs" 526
Downthrow 60
Down tube 360
Dox formation 277
dpi (Dots Per Inch) 570
Draco 19, 20
Draft mark
Frigate 397
Wooden sailing ship 379
Drafts folder 576
Draft tube 314
Drag
Biplanes and triplanes 402
Cycling 360
Early monoplane 400
Early passenger aircraft 406
Drag knob 563
Drag link
19th century paddlesteamer 391
Ford Model T 339
White Steam Car 342
Dragon prowhead 374
Drag spindle 562
Drag washer 562
Drainage systems divide 289
Drain mast 412, 415
Drain-pipe 492
Drain plug 339
Drakensberg 265
Dravidian finial 491
Dravidian style 490
Drawbridge 493
Drawbridge windlass 467
Drawing 430-431
Drawing board 430, 444-445
Drawing instruments 430
Drawing materials 430
Dreadnought-type battleship 394
Dressing-room 477
Dribbling
Basketball 532
Gaelic football 528
Handball 534-535
Soccer 524
Drill 600-601
D ring 46-47
Drip-cap 482
Drive 543
Drive belt 354, 335, 344, 362
Drive bracket 405
Drive chain 366, 368
Drive end 317
Drive gear 411
Driven gear 410
Driven pulley 335
Drive pillar 424
Drive plate 345
Drive point 346
Driver 547
Driver protection 357
Driverless train 328
Driver's platform 324
Driver's radio aerial 357
Driver's seat
Bordino Steam Carriage 335
"Deltic" diesel-electric locomotive 327
"Mallard" express steam locomotive 325
Paris Metro 328
Drive shaft
Jet engine 419
Renault Clio 351
Volkswagen Beetle 340
Drive sprocket mounting spline 366
Drive-wheel 601
Driving band 397
Driving chain 335
Driving pulley 335
Driving rein 555
Driving saddle 555
Driving sprocket 335
Driving wheel 324-325
Drizzle 302
Dromiceiomimus 86
Droop nose 416
Droop stop 422-423
Drop 381
Drop arm
Ford Model T 339
White Steam Car 342
Drop-down window 334
Drop glass 341
Drop goal 530
Drop handlebar 361
Dropkick 530
Drop tank 408
Drop window 332
Drowned coastline 294-295
Drowned valley 295
Drum 486
Ancient Greek building 460
Baroque church 481
Cathedral dome 487
Relief printing press 449
Washer-dryer 595
Drum and door seal 595
Drum brake
BMW R/60 362
Motorcycle 364-365
Vespa Grand Sport 160
Mark 1 363
"Windcheetah" racing HPV bicycle 361
Drumhead 387
Drum inlet elbow 595
Drumlins 286
Drum pad 520
Drums 518-519, 520
Drum suspension springs 595
Drupelets 146-149
Drupes 131, 148-149
Dry air 303
Dry brush 438-439
Dry capacity measurements 590
Dry fresco 434-435
Dry fruits 150-151
Couch grass 113
Durmast oak 131
Sycamore 131
Dry gallery 284-285
Drying agent 313
Dry lake bed 283
Dryland plants 156-157
Dryopteris filix-mas 120-121
Dryosaurus 70
Dry pericarps 150
Dry season 293
Dry wash 283
Dual click gear 562
Dual ignition plug 427
Dual seat 364
Dubhe 18
The Plough 19
Dubika 490
Duck 188
Duck-billed platypus 206-207
"Duckbills" 96
Duct 496, 497
Duct of Bellini 256
Ductus deferens 259
Dugout 536
Dumb iron 336, 342
Dummy front door 339
Dunkeld wet fly 563
Duodenum
Bird 189
Cow 198
Elephant 200
Frog 182
Human 215, 248-249
Rabbit 196
Tortoise 187
Duplex tubular cradle frame 363
Duradon 384
Dura mater 223, 237, 240
Durmast oak 131
Dust
Asteroids, comets, and meteoroids 52-53
Mars 42-43
Moon 41
Nebulae and star clusters 16-17
NGC 2997 (spiral galaxy) 12
Overhead view of our galaxy 14
Solar system 30
Venus' atmosphere 37
Dust cap 359
Dust cloud
Geological time 56
Large Magellanic Cloud 12
Mars 42-43
Milky Way 14-15
Nebulae and star clusters 16-17
Origin and expansion of universe 11
Volcano 272
Dust collection bin 592
Dust lane
Centaurus A 13
Horsehead Nebula 16
NGC 2997 (spiral galaxy) 12
Optical image of Rings and dust lanes 48
Trifid Nebula 16
Dust particles 53
Dust shroud 340
Dust storm 43
Dust tail 52-53
Dutch cubist style 495
Dutch shoe 377
Dutch triple fiddle block 383
DVD/CD control buttons 585
DVD/CD drive turntable 585
DVD/CD laser-reader 585
DVD/CD on-screen menu display button 585
DVD/CD processor microchip 585
DVD/CD sliding tray 585
DVD/CD stop button 585
DVD display button 585
DVD player 584-585
Dwarf crocodile 82
Dwarf shoot 124-125
Dynastes hercules 12
Dyson DC05 vacuum cleaner 592-593
Dysprosium 311

E

Ear
Calligraphy characters 445
Elephant 200
Gorilla 203
Hare 196
Horse 198
Human 210, 212, 242-243
Kangaroo 207
Rabbit 196
Rat 196
Eardrum
Chick 193
Frog 182
Human 243
Lizard 184
Earles fork 362
Early desertification 57
Early engines 342-343
Early English
Perpendicular-style tracery 472
Early English-style window 472
Early monoplanes 400-401
Early passenger aircraft 406-407
Early tram 332
Early voyagers 374-375
Earphone 586
Earpiece 588
Earplug 558
Earth 38-39
Cretaceous period 73
Energy emission from Sun 22
Jurassic period 71
Objects in universe 11
Phases of the Moon 41
Primitive life 78-79
Quaternary period 77
Solar eclipse 32
Solar system 30
Tertiary period 75
Tides 297
Triassic period 69
Earth-ball fungus 115
Earth bank 603
Earth connection 598
Earth formation 56-57
Earth pigments 434
Earthquake anatomy 63
Earthquake region 39
Earthquakes
Crustal movement 58
Faults and folds 60
Mountain building 62-63
Earth's atmosphere 38-39, 78, 300-301
Earth's composition 39
Earth's core 38-39, 63
Earth's crust 38-39, 58-59
Igneous and metamorphic rocks 274
Lake formation 292
Volcano 272
Earth's crustal plates 62, 64
Earth's energy 314
Earth's evolution 56-57
Earth's external features 39
Earth's formation 38, 56, 64
Earth's interior
Ocean floor 298
Rock cycle 266
Structure 39
Earth's layers 38
Earth's magnetic field 38
Earth's mantle 38-39, 58-59
Earth's orbit 297
Earth's physical features 264-265
Earth's rotation 38
Atmospheric circulation and winds 300
Oceans and seas 296
Satellite mapping 264
Earth's satellite 38
Earth's surface
Atmosphere 300-301
Earth's physical features 264
Formation of the Earth 38-39
Geological time 56
Mineral resources 280
Mountain building 62
Oceans and seas 296
Precambrian to Devonian period 64
Rock cycle 266
Earth's tilt 38
Earth wire 594
Earwig 168
East Africa 331
East Asian buildings 490-491
East Australian current 297
East Greenland current 296
Eaves
Ancient Greek building 461
Ancient Roman building 462, 464
Islamic tomb 489
Modern building 499
Neoclassical building 482
Renaissance building 477
Eaves board 490
Eccentric 392
Eccentric rod 391
Eccentric rotor journal 347
Eccentric shaft 347, 411
Eccentric-shaft bearing 410
Echidna nebulosa 180
Echidnas 206
Echinocactus grusonii 156
Echinoderms 174, 279
Echinus 460
Echinus escelentus 175
Echo-sounding 298
Ecliptic
Inclination of planetary orbits 31
Stars of northern skies 18-19
Stars of southern skies 20-21
ECM 355
Ecphora 75
Ectoderm 167
Eddy Merckx racing bicycle 360-361
Edible sea urchin 175
Edmontonia 95
Eel 180
EEPROM memory chip 587
Efferent arteriole 256-257
Effervescence 312
Effort 320-321
Egg cells 606-607
Eggs 192-193
Amphibian 78, 80
Baltimore oriole 193
Bee hummingbird 193
Bird 188
Butterfly 168
Capsule 192
Carrion crow 193
Case 192
Chaffinch 193
Chicken 192
Common tern 193
Dinosaur 82
Dogfish 192
Frog 182-183, 192
Giant stick insect 192
Greater backblacked gull 193
Hatching 192-193
Human 258, 260
Indian stick insect 192
Leaf insect 192
Maiasaura 98
Membrane 193
Ostrich 193
Quail 192-193
Reptile 66, 184
Titanosaurid 91
Willow grouse 193
Egg tempera 432
Egg-tooth 192-193
Egg white 192
Egg yolk binding medium 432
Egypt 331
Egyptian building 458-459
Eichhornia crassipes 158
Eighteenth-century building 492
Baroque 481
Neoclassical 478, 482-483
Eighth-century building 490-491
Einsteinium 311
Eisila Regio 36-37
Ejaculatory duct 259
Ejecta
Degas and Bronte 34
Features of supernova 27
Ray crater 34
Venusian craters 32
Ejector assembly 599
Ejector exhaust 408
Ejector-seat roof hatches 421
Ekeing 381
Ekman spiral 296-297
El-Ainyi Mosque 488
Elapsed time display 577
Elasmobranchs 178
Elastic fiber 252, 254
Elastic rocks 60

Elbow
Anchisaurus 89
Corythosaurus 98
Edmontonia 95
Gorilla 205
Horse 199
Human 210
Iguanodon 97
Lion 194
Psittacosaurus 103
Stegoceras 101
Stegosaurus 92
Triceratops 102
Elbow guard 553
Elbow joint
Brachiosaurus 91
Diplodocus 90
Eryops 80
Euoplocephalus 94
Human 218
Parasaurolophus 99
Plateosaurus 88
Stegoceras 101
Triceratops 102
Tyrannosaurus 84
Elbow pad 527, 551
Elder 130-131, 140 143
Electrical braking 330
Electrical cells 316-317
Electrical charge imbalance 316
Electrical circuit 316
Toaster 598
Electrical contact 319
Electrical effects 316
Electrical energy 314-315
Electrical harness 414
Electrical inverter 422
Electrical plant 496
Electrical relay 596
Electrical relay box 330
Electrical service compartment 407
Electrical supply 316
Electrical wiring harness 418
Electric bass guitars 512
Electric cable 517
Electric car 342
Electric charge 308
Electric coil 317
Electric current 316-317, 328. 603
Electric equipment compartment 329
Electric fuel pump 422
Electric generator 317
Electric guitar 512-513
Electric heating elements 597
Electric ignition control 362
Electricity 316-317
Electricity connector to brushbar motor 593
Electricity generation
Diesel train 326
Electric train 326
Magnetism 317
Electricity supply 590
Electric locomotive 324, 328-329
Electric motor
Diesel train 326
Electric train 328
Tram 332
Electric motor/generator 357
Electric motor housing 354
Electric power line 328, 402
Electric power socket 422
Electric scoring system 556-557
Electric street tramway 332
Electric toaster 598
Electric train 328-329
Electric transmission 326
Electric trolley 332
Electric window motor 349
Electrode 306
Electromagnet 317, 598
Electromagnetic induction capacitor 600
Electromagnetic radiation 314-315, 318
Electromagnetic spectrum 318-319
Electron 308, 316
Atomic number 310
Fluorine-19 309
Electron beam 611
Electron detector assembly 611
Electron gun 611
Electron gun housing 610
Electron microscope 610
Electronic controller 605
Electronic control signals 330
Electronic control-unit connector 356
Electronic drums 520
Electronic engine control (EEC) unit 418-419
Electronic games 578-579
Electronic ignition unit 351
Electronic impulses 584
Electronic instruments 520-521
Electronic signals 512
Electronic warfare mast 397
Electrons 605
Electron shell 308-309, 310
Electron stream 611
Electron transfer 308
Electrostatic forces 308, 316
Electrostatic generator 316
Electrothermal de-icing panel 416
Element retaining stop 599
Elements 306, 308
Atomic mass 310
Minerals 268
Periodic table 310-311
Elephant 90, 104, 200-201
Elephas maximus 200
Elevated green 546
Elevating wheel 396
Elevation 498
Elevator
ARV light aircraft 424
BAe-146 components 415
Bell-47 helicopter 423
Biplanes and triplanes 402-403
Curtiss biplane 399
Early monoplanes 400-401
Hawker Tempest components 409
Schleicher glider 426
World War 1 aircraft 405
Wright Flyer 399
Elevator arm 425
Elevator chassis box 415
Elevator control cable 399, 403
Elevator control rod 409
Elevator control wire
Bell-47 helicopter 47
Bleriot XI monoplane 401
Curtiss biplane 399
LVG CVI fighter 405
Elevator drive wheel 399
Elevator hinge
BAe-146 components 415
BE 2B tail 405
Blackburn monoplane 400
Hawker Tempest components 409
Elevator operating arm 399
Elevator-operating bracket 401
Elevator push-rod 424-425
Elevator rocking arm 404
Elevator trimtab 424, 409
Elevator wire 398
Eleventh-century building 466, 468
Elevon 416-417, 421
Elevon-jack fairing 416
Elevon power control unit 417
"Ellerman Lines" steam locomotive 324-325
Elliott steering knuckle 336
Ellipsoid orb 486
Elliptical galaxy 11-12
Elliptical orbit 30
Elliptic leaf 137
Elm 144, 150
El Nath 18, 21
Elodea canadensis 158-159
Elodea sp. 159
Elongating root 133, 153
Elrathia 64
Eltanin 19
Elytron 168
Email 576, 577
Email address 576
Email program 576, 577
Email sender 576
Emarginate apex 136
Embellisher 353
Embolos 372
Embrasure 466-467, 469
Embryo 607
Cotyledon 152-153
Dry fruit seed 150-151
Fertilization 146-147
Germination 152-153
Human 260
Reptile 80
Seed leaf 152
Succulent fruit seed 148-149
Embryonic root 150, 152-153
Embryonic shoot 147
Epigeal germination 153
Hypogeal germination 152
Pea seed 150
Pine 122
Seed axis 152-153
Embryo sac 146-147
Emergency canopy release handle 420
Emergency door control 332-333
Emergency escape hatch 406
Emergency exit 416-417
Emergency oxygen cylinder 417
Emergent coastlines 294-295
Emission nebula 11-12, 14, 16-17
Empire State Building 494
Enamel
Islamic buildings 488-489
Teeth 247
Enceladus 46
Encke 40
Encke Division 46-47
Enclosed bridge 397
Enclosed DVD/CD compartment 585
Encroachment 527
End 388-389
End baffle plate 598-599
End block 512
End effector 608
EN-EL12 rechargeable battery 581
End element 598-599
End-grain wood block 449
End-line
Basketball 532
Football 526
Men's Lacrosse 540
Volleyball 534
End link 386
Endocardium 250
Endocarp 146-147, 148-149
Endoderm 167
Endodermis
Bishop pine needle 124
Canadian pond weed stem 158-159
Dicotyledon 127
Epiphytic orchid 162
Fern rachis 121
Horsetail stem 120
Mare's tail stem 135
Monocotyledon 127
Pine root 125
Root 132-133
Water hyacinth root 158
Endomysium 228
Endoperidium 115
Endoplasmic reticulum 239
Endopod 172
Endoscopic view
Alimentary canal 248
Vocal cords 245
Endoskeleton 174
Endosperm 147
Endosteum 225
Endothecium 144
Endothelium 252
End-pin 510
End-plate
Formula One race car 356-357
Modern piston aero-engine 410-411
End-plate aerodynamic skirt 357
End zone 526
En echelon fractures 60-61
Energized electrode 584
Energy 314-315
Chemical reactions 312
Electron shells 310
Light 318
Renewable 604-605
Energy conversion 138
Energy emission from Sun 22
Engaged column 469
Engaged pediment 462-463
Engine 342-347, 410-411, 418-419
1906 Renault 337
1-liter VTEC 354
72° V10 356
ARV light aircraft 425
BAe-146 jetliner 415
BMW R/60 362
Bordino Steam Carriage 334
Diesel 326
Early monoplane 400-401
Hawker Tempest components 408
Helicopter 422-423
Honda CB750 363
Honda VF750 364
Kirby BSA 369
Lockheed Electra airliner 406-407
Motorcycles 362, 364, 366-367
Oldsmobile engine 336
Pegasus Quasar ultralight 427
Pioneers of flight 398-399
Renault Clio 350-351
Velocette overhead valve (OHV) 367
Volkswagen Beetle 340
Engine aft bulkhead 421
Engine air intake
BE 2B bomber 404
Concorde 416
Formula One race car 356, 357
Hawker Tempest fighter 409
Schweizer helicopter 423
Tornado 420
Engine and propeller thrust frame 398
Engine bearer 343
Engine block 347
Engine cover
Formula One race car 356, 357
Honda VF750 374
Oldsmobile bodywork 337
Two-stroke engine 366
Vespa Grand Sport 160
Mark 1 363
Volkswagen Beetle 341
Engine cowling
Airbus 380 573
ARV light aircraft 424-425
Avro biplane 403
Concorde 416
Hawker Tempest components 408
Lockheed Electra airliner 407
Pegasus Quasar ultralight 427
Engine crankcase 327
Engine drive belt 354
Engineering 496
Engine front mount 418-419
Engine front support link 417
Engine fuel pump 417
Engine instruments 425
Engine lid 341
Engine lifting eye 347
Engine mounting
ARV light aircraft 425
Blackburn monoplane 401
Honda VF750 364
Modern piston aero-engine 411
Pegasus Quasar ultralight 427
Velocette OHV engine 367
Engine pylon 412
Engine rear mount
Pegasus Quasar ultralight 427
Turboprop engine 419
Engine room 326
Engine timing gear 336
Engine warning display 573
Englacial moraine 287
Englacial stream 286
England 92
English baroque style 480-481
English bond brickwork 485
English Decorated style 470
English ivy 131
English Perpendicular style 470, 472
Engraving 446
Enif 19, 20
Pegasus and Andromeda 19
Ensign staff 396
Entablature
Ancient Greek building 460
Ancient Roman building 462-465
Baroque church 480-481
Cathedral dome 487
French temple 485
Neoclassical building 478-479, 482-483
Entasis 461
Enter button 585
Enter key 590
Enteromorpha linza 117
Entomophilous pollination 144
Entrance
Islamic tomb 489
Medieval building 466-467
Modern building 496-499
Neoclassical building 483
Nineteenth-century building 493
Twentieth-century building 494
Entrenched meander 290
Entresol 467
Enucleated egg cell 606
Enzyme 160
Eocene epoch
Fossil record 279
Geological timescale 57
Eon
Fossil record 279
Geological time 56-57
Epée 556-557
Epibranchial artery 179
Epicardium 250
Epicenter 63
Epicotyl 152-153
Epicranial aponeurosis 237
Epidermal cell 166
Epidermis
Apical meristem 134
Canadian pond weed stem 159
Clubmoss stem 120
Dicotyledon 126-127
Epiphytic orchid 162
Fern rachis 121
Flower 142
Horsetail stem 120
Human 234-235
Leaf 139
Marram grass 113
Monocotyledon 126-127
Moss 119
Multilayered 162
Pine needle 124
Pine stem 125
Prickle 135
Radicle 152
Rhizome 155
Root 132-133
Stem 134-135
Water hyacinth 158
Water lily 159
Epididymis 259
Epidote 269
Epigeal germination 152-153
Epiglottis
Elephant 200

Human 212, 244-245, 248, 255
Epiphysis 230
Epiphytes 112, 162-163
Epithelial cell 217
Epithelium 254
Epoccipital bone 102
Epoch
Fossil record 279
Geological time 56-57
Epoxy resin frame 612
Epsilon Centauri 21
Epsilon Crucis 21
Epsilon Hydri 20
Epsilon ring 48-49
Epson Stylus Photo 895 color inkjet printer 574
Equal-shock intensity lines 63
Equator
Atmosphere 300
Quaternary period 76
Saturn 47
Satellite map 265
Surface currents 297
Equatorial air 300
Equatorial current 296-297
Equatorial furrow 144
Equatorial Zone 45
Equestrian sports 554-555
Equisetites sp. 66
Equilateral triangle 622
Equisetum arvense 70, 120
Equuleus 19, 20
Era
Fossil record 279
Geological time 56-57
Eraser 450
Erasing stick 448
Erbium 311
Erect limb stance 82
Erh-wei 376
Eridanus 19, 20
E ring 46
Erosion 282-283
Coastline 294-295
Lake formation 293
Ocean floor 298
River features 290-291
Rock cycle 267
Sedimentary rocks 276
Eryops 80-81
Escalator 497-498
Escape/back button 589
Esker 286
Esophagus
Barnacle 173
Bird 189
Brachiosaurus 91
Butterfly 169
Chimpanzee 202
Cow 198
Dogfish 179
Dolphin 205
Domestic cat 195
Elephant 200
Human 212, 215, 245, 248
Lizard 185
Rabbit 196
Snail 177
Spider 170
Starfish 174
Tortoise 187
Estonioceras perforatum 65
Estuarine mud-flat 295
Estuary 288, 290-294
Eta Centauri 21
Eta Mensae 20
Eta Orionis 18
Eta ring 48
Eta Sagittarii 21
Etching 446
Ethernet port 566
Euathlus emilia 170
Euoplocephalus 94-95
Eurasia 76
Eurasian plate 59
Europa 44
Europe
Cretaceous period 72-73
Earth's physical features 264-265
Electric train 328
Electric tram 332
Jurassic period 70
Loading gauge 331
Middle Ordovician period 64
Quaternary period 76
Railroad track gauge 331
Tertiary period 74-75
Triassic period 68
European field elm 144
European hard-screw coupling 402
Europium 311
"Eurostar" multivoltage electric train 328-329
Eurypterid fossil 79
Eustachian tube 243
Eustreptospondylus 85
Euthynteria 460
Evacuated column 610, 611
Evaporation 307
Event horizon 28-29
Evergreens 130-131
Everlasting pea 129
Evolute shell 278
Evolution
Earth 56-57
Living things 278
Excretory pore 177
Excurrent pore 166
Exfoliation 282
Exhaust
Catalytic converter 355
Ford diesel engine 347
Modern mechanics 350-351
Paddlesteamer 391
Exhaust clamp 362
Exhaust collector ring 403, 406
Exhaust cone 419
Exhaust connection 427
Exhaust diffuser 418
Exhaust downpipe 350
Exhaust fairing 419
Exhaust gas recirculation valve 344
Exhaust heat shield 345
Exhaust manifold
1906 Renault 337
ARV light aircraft 425
Jaguar V12 engine 345
Mid West two-stroke engine 410
Renault Clio 351
Exhaust nozzle 418
Exhaust pipe
Avro biplane 403
Bell-47 helicopter 422
BMW R/60 362
Brazilian battleship 395
Harley-Davidson FLHS Electra Glide 363
Formula One race car 356
Hawker Tempest fighter 409
Honda CB750 363
Honda VF750 364
Kirby BSA 369
Lockheed Electra airliner 406-407
Oldsmobile engine 336
Pegasus Quasar ultralight 427
Suzuki RGV500 368
White Steam Car 342
World War I aircraft 404-405
Exhaust pipe flange 411
Exhaust port
"Deltic" diesel-electric locomotive 326
Four-stroke cycle 343
Mid West 75-HP engine 410
Two-stroke engine 367
Velocette OHV engine 367
Wankel engine 347
Wankel rotary cycle 346
Exhaust silencer 423, 427
Exhaust stack 405
Exhaust steam water injector control 325
Exhaust stroke 343
Exhaust system 368
Exhaust tract 410
Exhaust valve 345-345
Exhaust valve push-rod 400
Exhaust vent
British Rail Class 20 diesel engine 327
Drill 601
"Union Pacific" locomotive 326
Exine 144-145
Exit door 333
Exocarp 146-149
Exoccipital bone 183
Exocet missile launcher 397
Exodermis 162
Exoperidium 115
Exopod 172
Exoskeleton
Insect 168
Malacostraca 172
Spider 171
Exosphere 300
Exothermic reactions 312
Expander bolt 359
Expandible sponge 448
Expansile jaw 85
Expansion lever 325
Expansion of sail 378-379
Expansion slot 567
Expelling plate 397
Expiration 255
Exploding shell 396, 397
Expressionist style 495
Extended cave system 285
Extended port air-brake 421
Extensor digitorum brevis muscle 233
Extensor digitorum longus tendon 233
Extensor digitorum tendon 231
Extensor hallucis brevis muscle 233
Extensor hallucis longus tendon 233
Extensors of hand 227
External anatomy
Body 210-211
Brain 237
Ear 242-243
Foot 233
Hand 231
Sperm 259
External auditory meatus
Homo erectus 108
Homo sapiens 108, 220, 242
External crust 28
External elastic lamina 252
External iliac artery 215, 225, 253
External iliac vein 215, 253
External monitor port 567
External nostril 184
External oblique muscle 226
External occipital crest 220
External pubo-ischio-femoral muscle 97
External skeleton
Insect 168
Malacostraca 172
Spider 171
External spermatic fascia 259
External urinary meatus 258
Extinct geyser 275
Extinction
Dinosaur 56, 74, 82, 104
Life 66
Pleistocene mammals 76
Extinct volcano 62, 272
Igneous rock structures 275
Mountain building 62
Ocean floor 298
Extrados 484-485
Extra period 532
Extrusive rocks 274, 275
Eye
Allosaurus 85
Amphibian 182
Anchisaurus 89
Angling hook 562
Beetle 168
Bird 188
Bony fish 181
Brachiosaurus 91
Bumblebee 168
Butterfly 169
Caiman 186
Carnivore 194
Chick 192-193
Corythosaurus 98
Crab 172
Crayfish 173
Crocodilian 186
Deer hopper dry fly 563
Devon minnow 563
Dhow 376
Dogfish 178
Dolphin 204
Elephant 201
Figurehead 374
Forward-facing 194
Frog 182
Gallimimus 86
Gorilla 203
Greek and Roman ships 372
Herrerasaurus 86
Horse 198
Human 211, 212, 240-241
Iguanodon 97
Kangaroo 207
Knot 388
Lamprey 178
Lion 194
Lizard 184
Median 170
Octopus 177
Pachycephalosaurus 100
Psittacosaurus 103
Rabbit 196
Rat 196
Rattlesnake 185
Rigging 382-383
Salamander 182
Scallop 176
Scorpion 170
Seal 204
Shrimp 172
Simple 170-171
Snail 177
Snake 185
Spider 170
Stegoceras 101
Stegosaurus 92
Terrapin 187
Triceratops 102
Trilobite fossil 78
Tyrannosaurus 84
Westlothiana 87
Eyeball 241
Eye bolt 381
Eyebrow
74-gun ship 381
Human 212
Eyelash 212
Eyelid
Caiman 186
Human 213
Snake 184
Terrapin 187
Eyepieces 610, 611
Eye plate lug 382
Eyespot 116

F

F-14 Tomcat fighter 420
Fabric 384
Fabric covering
Aluminum and steel wing 403
BE 2B tail 405
Blériot XI monoplane 401
Steel-tube fuselage 403
Fabric lacing 405
Fabric skin 401
Fabric softener section 595
Fabry 41
Facade
Ancient Greek building 461
Ancient Roman building 465
Baroque church 480-481
Gothic church 470-472
Modern building 496-499
Neoclassical building 478, 483
Nineteenth-century building 493
Renaissance building 474
Facade pediment 481
Facade wall 470
Face
Deadeye 383
Human 211
Sailmaker's mallet 384
Face mask
Fencing 557
Football 526
Hockey goalkeeper 540
Ice hockey goalkeeper 550
Lacrosse goalkeeper 541
Slalom skiing 553
Facet 222-223
Faering 374-375
Fag end 387, 388
Fahrenheit temperature scale 590
Fairing 364, 369
Fairing of landing gear 413
Fairing panel 415
Fairlead
Battleship 395
Frigate 397
Rigging 383
Roman corbita 373
Fairway 546
Falciform ligament 248
Falco tinnunculus 189
Falkland current 296
Fall 382
Fallopian tube 258-259, 261
False acacia 136
False anthers 141
False door 458-459
False fruit 148-149
False ram bow 394
"False ribs" 218
False septum 151
Falx cerebri 237
Fan
Jaguar straight six engine 344
Jet engines 418-419
Microwave combination oven 596-597
Power drill 600
Fan blade
Renault Clio 353
Turbofan 419
Fancase 418
Fan drive shaft 345
Fan duct nozzle 412
Fan dust shield 597
Fan fold 61
Fang 170
Fan transformer 597
Fan motor 351
Fan vault 484-485
Farming ax 109
Fascia
Ancient Roman building 463-464
Baroque church 479, 481
Cellphones 589
Dome 486
French temple 485
Gothic building 472
Medieval building 467, 469
Modern building 498
Neoclassical building 482
Renaissance building 476-477
Renault Clio 353
Fast forward button 577
Fat
Cells 217
Tissue 215, 235
Faultline
Lake formation 292
Mountain building 62-63
Weathering and erosion 283
Fault plane 60
Faults 60-61, 292
Mineral resources 280
Mountain building 62
Oil and gas traps 281
Showjumping competitions 554
Fault spring 292
Fault structure 60
Fault trap 281
Fava bean 133, 152
F-block 311
FCC cable 571
F clef 502
Feather 188, 191
Feathered float 391
Feathering 440-441
Feather shuttlecock 544-545
Feather star 174
Feed add button 577
Feed bilge pump 391
Feeder station 328
Feed list 577
Feed name 577
Feet
Human 232-233
Theropods 84
Fei Tecnai G2 transmission electron microscope 610
Feldspar 267, 269, 275
Felloe 390
Felt blanket 447

Felt-covered beater 516 518-519
Felt-tip pen 444
Female
Body 210, 211
Pelvis 218, 258
Reproductive organs 259
Female apex 119
Female cones
Bishop pine 124
Gymnosperm 122
Pine 122, 124
Smooth cypress 123
Yew 123
Female flower organs 140-143
Female flower remains 148
Female flowers 143, 144, 148
Female gametes
Fertilization 146-147
Gymnosperm 122
Seots pine 122
Seaweed 116-117
Yew 123
Female receptacles 117
Female reproductive organs
Fern 121
Fruit 148
Moss 119
Plants 144
Femoral artery 225, 253
Femoral musculature 86
Femoral nerve 238
Femoral vein 253
Femoro-tibial muscle 84
Femur
Albertosaurus 84
Archaeopteryx 85
Beetle 168
Bird 189
Brachiosaurus 90
Butterfly 169
Crocodile 186
Dinosaur 82
Domestic cat 195
Elephant 201
Eryops 81
Euoplocephalus 94
Frog 185
Gallimimus 86
Hare 197
Horse 199
Human 218-219, 224-225
Iguanodon 96-97
Kangaroo 206
Kentrosaurus 93
Lizard 184
Parasaurolophus 98
Pareiasaur 81
Plateosaurus 88
Platypus 206
Rhesus monkey 202
Scorpion 170
Seal 204
Spider 171
Stegoceras 101
Stegosaurus 93
Struthiomimus 87
Toxodon 107
Triceratops 102
Tuojiangosaurus 93
Turtle 187
Tyrannosaurus 84
Fencing 556-557
Fender
1906 Renault 336-337
BMW R/60 with Steib chair 362
Cannondale ST 1000 touring bicycle 361
Ford Model T 338-339
Harley-Davidson FLHS Electra Glide 363
Honda VF750 364
Husqvarna Motocross TC610 368
Kirby BSA 369
Lockheed Electra 406
Motorcycle 364
Suzuki RGV500 369
Volkswagen Beetle 341
Weslake Speedway motorcycle 369
Fender eye bolt 339
Fender jazz bass guitar 513
Fender stay 337, 362, 363
Fender stratocaster guitar 513
Fenestration 474, 494
Fermentation 313
Fermium 311
Fern 120-121
Fossil 66, 279
Life-cycle 121
Prehistoric Earth 68, 70, 72
Tree fern 112-113
Ferrel cell 300
Ferrite core 571
Fertile horsetail stem 120
Fertile oasis 283
Fertilization 146-147
Fern 121
Gymnosperm 122
Scots pine 122
Seaweed 117
Festoon
Ancient Roman building 462-463
Cathedral dome 487
Neoclassical building 478-479
Fetal skull 220
Fetlock 199, 554
Fetus 260-261
Fiber 134-135
Fiberglass 548
Bow 548
Bucket seat 361
Canopy frame 425
Fuel tank 425
Racket 544
Reinforced plastic cover 329
Wheel guard 369
Fiber insulation 602
Fiber plate 366
Fibrils 32
Fibrin 253
Fibrous capsule 256
Fibrous habit 271
Fibrous pericardium 250
Fibrous septum 245
Fibula
Albertosaurus 84
Brachiosaurus 90
Crocodile 186
Diplodocus 90
Domestic cat 195
Elephant 201
Eryops 81
Euoplocephalus 94 87
Hare 197
Horse 199
Human 219, 232-233
Iguanodon 96-97
Kangaroo 206
Lizard 184
Parasaurolophus 99
Plateosaurus 88
Platypus 206
Rhesus monkey 202
Seal 204
Stegoceras 101
Stegosaurus 93
Struthiomimus 87
Toxodon 107
Triceratops 102
Turtle 187
Tyrannosaurus 84
Fibulare 183
Ficus carica 148
Ficus sp. 137
Fid 385, 384
Fiddle block 378, 383
Field arrow 549
Field coil 600
Fielder's glove 537
Field events 542
Field goal 526-527
Fielding 538
Fielding team 536
Field judge 526
Field positions 538
Fields and particles instruments 614
Field umpire 528
Fifteenth century
Mihrab 488
Renaissance building 474-475
Style 462, 470
Terrace 490
Tracery 472
Fig 137, 148
Fighters 404-405, 408-409, 420
Fighting 556
Fighting platform 374
Figurehead
74-gun ship 380-381
Wooden sailing ship 379
Figure-eight turns 387
Filament
Alga 116
Dicotyledon flower 126-127
Fern 121
Fertilization 146-147
Flowers 140-141, 143
Fungal 114-115
Jellyfish 167
Light bulb 319
Nebulae and star clusters 16-17
Sun 32-33
Moss 119
Pollination 144
Filbert hog hair brush 436
File status indicator 577
Filicinophyta 120
Filiform papilla 244
Filing 455
Filled shell 310-311
Fillet
Ancient Greek temple 461
Dome 486
French temple 485
Gothic building 470
Neoclassical molding 480
Renaissance building 475, 477
Riling transom 381
Film and transparency holder 570
Filter 576
Filter access flap 594
Filter rim casing 592
Filter seal 595
Filter screw cover 595
Filter turret 610
Fimbria 258-259
Fin
Anal 178, 181
ARV light aircraft 424
Avro biplane 402
BAe-146 components 415
Blackburn monoplane 401
Caudal 178-181
Concorde 416
Devon minnow 563
Dorsal 178-179, 181, 205
Helicopter 423
Lockheed Electra airliner 407
Lungfish 81
LVG CVI fighter 405
Pectoral 178, 180-181
Pelvic 179-181
Schleicher glider 426
Tornado 421
Ventral 179
World War II aircraft 408-409
Final drive and gearbox 340
Final-drive sprocket 335
Fin-attachment skin 415
Find key 590
Fine leg 538
Fine linen canvas 437
Fine-toothed marble claw 453
Finger
Anchisaurus 89
Gorilla 203
Human 211
Iguanodon 97
Pachycephalosaurus 100
Psittacosaurus 103
Stegoceras 101
Theropod 84
Fingerboard 510-511, 513
Finger-claw 83, 85
Finger hole 508
Finger key 507
Fingerless glove 527
Fingernail 231
Finger recess 571
Finger tab 548
Finial
Asian building 490-491
Baroque church 479, 481
Gothic church 470-471
Islamic building 488-489
Medieval building 468
Neoclassical building 478
Nineteenth-century building 493
Renaissance building 476
Finish line 542, 554-555
Fin leading-edge attachment 415
Finned tail 80
Fin-root aerial fairing 421
Fin tip 415
Fin tip fairing 421, 424
Fin trailing edge 415
Fir 66
Fire 108
Fireball 10
Firebox 324-325
Fire-escape 497-498
Fire extinguisher 328
Fire-extinguisher discharge indicator 412
Fire-hole 325
Fire-making tools 109
Fireman's seat 325
Fire opal 270
Fireplace 466-467
Fire-resistant clay 454
Fire-resistant curtain 497
Fire-resistant panel 496
Fire-tube boiler 334
Fire tubes 324-325
Firewall 406, 425
Firewire ports 560
Firewire socket 587
Firing 452
Firing chamber 575
Firing pin 549
Firn 287
First century 462-464
"First down" 526-527
First pilot's seat 408
First quarter 41
First rate ship 378
First slip 538
First transition metals 310
First violin 503, 504-505
First wheel set 329
Fish
Bony 180-181
Breathing 180
Cartilaginous 178
Fossil 279
Holostean 73
Jawless 178-179
Fish davit 379
Fisherman's schooner 385
Fishing tackle 109
Fish-scale tile 476-477, 486
Fishtail nectaries 160
Fissure 247
Fissures 157
Fissure volcano 272
Five-line stave 502
Five yard mark 540
Fixative 430, 440
Fixed float 390
Fixed gear 346-347, 411
Fixed lug 383
Fixed-spool reel 562
Fixing screw 599
Fjord 294-295
Flagella 166
Flagellum
Beetle 168
Chlamydomonas sp. 116
Moss 119
Seaweed gametes 117
Snail 177
Sperm 259
Flag halyard 380
Flagmast 395
Flag pin 547
Flagpole 495
Flaking rock 282
Flamboyant tracery 472
Flame 312-313
Flamingo 188, 190
Flamsteed 40
Flange 492, 498
Flanged plate 425
Flank
Bird 188
Cow 198
Flanker
Canadian football 526
Rugby 530
Flank spike 95
Flap
ARV light aircraft 425
Formula One race car 356, 357
Hawker Tempest components 409
Lockheed Electra airliner 406
Tornado 421
Flap drive screw 413
Flap lever 425
Flap seal 413, 414
Flap tip 414
Flap torque tube 424
Flap track 413
Flap-track fairing 413, 415, 572, 573
Flared bell
Brass instruments 506-507
Woodwind instruments 508-509
Flash lamp 580
Flash steam generator 342
Flash tube 597
Flask 312-313
Flat
Musical notation 502
Twin bollards 386
Flatbed scanner 570-571
Flatboard 384
Flat bottom 391
Flat-bottomed rail 331
Flat chisel 452
Flat cone 272
Flatfish angling 562
Flat-four engine 340
Flat freight car 327
Flat horse-races 554
Flat laminae 138
Flat roof
Ancient Egyptian building 458
Neoclassical building 483
Twentieth-century building 494-495
Flat seam 384
Flat seizing 383, 389
Flat soffit 464
Flattened pericarp 151
Flattened petiole 160
Flattened stem 129
Flat-topped plateau 275, 282
Flat-topped seamount 298
Flat wire seizing 383
Flavian amphitheater 464
Flax-spinning mill 492
Fleet number 333
Flesh-eaters 194
Flesh-eating dinosaur 70
Flesh tones 433
Fleshy aril 148
Fleshy axis 143
Fleshy fruit 146-147
Fleshy hair 140
Fleshy infolded receptacle 148
Fleshy scale leaf 155
Fleteh 548
Flexible hose shrouding 593
Flexible ribbon cable 580
Flex kink guard 594
Flexor digitorum longus muscle 233
Flexor digitorum tendon 231
Flexor hallucis longus muscle 233
Flexor pollicis brevis muscle 231
Flexor retinaculum muscle 231
Flexors of forearm 226
Flexors of hand 227
Flexor tubercle 85
Flex rewind 593
Flight 543
Flight-control hydraulic jack 416
Flight-control mixing unit 417
Flight-control rod 423
Flight controls 412
Flightdeck door 573
Flightdeck windshield 573
Flight feathers 188, 191
Flight instruments 425
Flight refueling receptacle 421
Flint 277
Flint tools 108-109
Flipper
Dolphin 204
Seal 204
Flitch-plated wooden chassis 342
Float 390-391
Floating disc brake 364-365
Floating floor 602
"Floating" rib 218
Flocked pastel board 441
Floodgate 604
Flood-plain 289-291
Floods 290
Floor
Gun turret 396

Ironclad 393
Longboat 380
Modern building 496-498
Nineteenth-century building 492
Twentieth-century building 494-495
Floor anchor 407
Floorboard 464, 486
Floor-joist 464
Floor-mounted base 608
Floor pan 340
Floor torn 518-519
Florence Cathedral 475, 487
Florets 142
Florists' chrysanthemum 129
Ultraviolet light 145
Florida current 296
Florists' chrysanthemum 129
Flower bud
Aechmea miniata 162
Broomrape 163
Bulb 155
Clematis 131
Florists' chrysanthemum 129
Hibiscus 127
Ice-plant 129
Live-forever 129
Oxalis sp. 157
Peruvian lily 129
Rose 131
Water lily 159
Wind pollination 144
Flowering plant 57, 70, 72
Flowering shoot 155
Flowers 140-143
Brassavola nodosa 162
Bromeliad 113
Broomrape 163
Buds 140-141, 143
Clematis 131
Color 140, 144-145
Dicotyledons 126-127, 141-143
Dodder 163
Epiphytes 162-163
Everlasting pea 129
Florists' chrysanthemum 129
Guzmania lingulata 163
Ice-plant 129
Involucre 129
Monocotyledons 126, 140-141, 143
Peruvian lily 129
Pollination 144-145
Rose 131
Russian vine 131
Scented 144
Stem arrangements 143
Ultraviolet light 145
Vegetative reproduction 154
Water lily 159
Yew 123
Flower scars 154
Flower spike 143, 155
Flower stalk
Brassavola nodosa 162
Bulbil 154
Clematis 131
Dry fruit 150-151
Fertilization 146-147
Florists' chrysanthemum 129
Fruit development 146-147
Monocotyledons 140-141, 143
Oxalis sp. 157
Rose 131
Rowan 131
Russian vine 131
Succulent fruit 148-149
Sycamore 131
Water lily 159
Flow splitter 418
Fluff filter impeller 595
Fluid 306
Fluke
74-gun ship 380
Danforth anchor 386
Fluorescent light 318-319
Fluorine 308-309, 311
Fluorite 271
Halides 269
Flush-riveted aluminum fuselage 423
Flush-riveted metal-skinned wing 406
Flush window 494
Flute 503, 504-505, 508
Fluted pilaster 462
Fluted pinnacle 481
Fluted shaft 478
Flute tube 325
Fluting 461, 463
Flutter kick 559
Fly 168
Fly-by-wire side stick 573
Fly fishing 562
Fly-half 530
Flying boat 406
Flying buttress
Gothic building 470-473
Medieval building 466, 468-469
Nineteenth-century building 493
Flying Fortress bomber 408
Flying helmet 404
Flying jib 385
Flying reptile 70
Flying tackle 531
Fly rod 562-563
Flywheel
Benz Motorwagen 335
Early engines 342-343
Etching press 447
Mid West rotary engine 411
Oldsmobile engine 336
Renault Clio 351
Steamboat 391
Flywheel retaining thread 411
Flywheel with balance weight 347
FM and TV aerial 603
Focker, Anthony 404
Fo'c'sle 380
Focus 63
Focusing lens 581
Fog 42-43
Fog-lamp 349, 353
Fog light 332, 363
Foil 556-557
Foilist 557
Foil pommel 557
Folded rock 60, 266
Impermeable rock 281
Mineral resources 280
Strata 60-61
Folded schist 274
Folding foot rest 572
Folding mountain range 274
Folding step 326
Folding table with integral keyboard 573
Fold mountains 62
Fold of mucous membrane 249
Folds 60-61
Foliage leaf
Bishop pine 124
Bud 124
Bulb 155
Germination 152-153
Monocotyledon 126
Parasitic plant 162
Pine 124-125
Rhizome 155
Seedling 152-153
Stem bulbil 155
Yew 123
Foliated capital 469
Foliated frieze 469, 479
Foliated panel 479
Foliated scrollwork 472
Foliated volute 476
Foliate papilla 244
Foliose lichen 114
Foliose thallus 114
Follicle
Dehiscent dry fruit 150-151
Hair 235
Ovary 258
Fomalhaut 19, 20
Fontanelle 220
Font color button 576
Font menus button 576
Food storage
Bulb 155
Corm 155
Embryo 147
Rhizome 155
Root tuber 155
Scale leaf 155
Seed 152
Succulent 156-157
Swollen stem 113, 155
Foot
Anchisaurus 89
Bird 190
Caiman 186-187
Corythosaurus 98
Cow 198
Diplodocus 90
Duck 188
Elephant 90
Gorilla 203
Harp 511
Herrerasaurus 86
Horse 198
Human 210
Iguanodon 96
Kangaroo 207
Pachycephalosaurus 100
Relief-printing press 449
Sails 374, 385
Slug 176
Snail 177
Stegoceras 101
Stegosaurus 92
Toaster 598-599
Tyrannosaurus 84
Tube 174
Webbed 188
Westlothiana 81
Football 524, 526-527
Footboard 335
Foot brake 363
Footbridge 493
Foot-fault judge 544
Foot mat 363
Foot pedal 366, 514
Footplate 324
Footrest
Curtiss biplane 398-399
Suzuki RGV500 368
Weslake Speedway motorcycle 369
Footrest hanger 364
Foot rope 378-379, 382, 385
Foot throttle 427
Foramen cecum 244
Foramen magnum 220
Foraminiferans 279
Force 320-321
"Force play" 536
Ford Cosworth V6 12-valve engine 344
Ford Cosworth V6 24-valve engine 344
Ford, Henry 338
Ford Model T 338-339
Ford turbocharged diesel engine 347
Fore-and-aft rigged lateen sails 376
Fore-and-aft sails 384
Fore-and-aft schooner 385
Forearm
Gorilla 203
Horse 199
Human 210
Movement 227
Forearm guard 548
Forearm pass 534
Fore bitt 380
Fore breast rope 387
Forecarriage 335
Forecastle
74-gun ship 380
Sailing warship 376
Square-rigged ship 375
Forecastle castle-deck gunport 376
Forefoot
Caiman 186
Diplodocus 90
Edmontonia 95
Elephant 90
Iron paddlesteamer 393
Stegosaurus 92
Fore hatch tackle 379
Forehead
Bird 188
Dolphin 204
Elephant 200-201
Horse 199
Human 211, 212
Foreleg
Caiman 186
Elephant 201
Lizard 184
Terrapin 187
Forelimb
Anchisaurus 89
Bird 188
Corythosaurus 98
Edmontonia 95
Frog 182
Hare 196
Herrerasaurus 86
Iguanodon 97
Kangaroo 207
Pachycephalosaurus 100
Psittacosaurus 103
Rabbit 196
Rat 196
Salamander 182
Stegoceras 101
Stegosaurus 92
Thyreophorans 92
Triceratops 102
Tyrannosaurus 84
Forelock 199
Fore lower topsail 385
Fore mast
Iron paddlesteamer 392
Roman corbita 372
Sailing warship 376
Square-rigged ship 375
Wooden sailing ship 379
Fore mast course 379
Foremast hole 380
Fore mast topgallant sail 379
Fore mast topsail 379
Forepeak 393
Fore royal stay 383
Fore sail 372, 385
Fore sail halyard 380
Foreset strata 283
Fore shroud 379
Foresight
Rifle 549
Target pistol 549
Foreskin 259
Fore spring rope 387
Fore stay
Rigging 382
Roman corbita 372
Sailing warship 376
Wooden sailing ship 379
Fore staysail 379, 385
Forest-dwelling mammals 74
Fore throat halyard 385
Fore top 379
Fore topcastle 376
Fore topgallant mast 379
Fore topmast 376, 379
Fore topmast stay 376, 379
Fore topmast staysail 385
Fore topmast staysail tack 382
Fore topsail 379
Fore upper topsail 385
Forewing 169
Fore yard 376, 379
Fore yard lift 385
Forged iron anchor 392
Fork
ARV Super 2 425
Eddy Merckx racing bicycle 361
Harley-Davidson FLHS Electra Glide 363
Honda CB750 363
Motorcycle 364
Vespa Grand Sport 160 Mark 1 363
Fork blade 359
Forked beam 380
Forked connecting-rod 342
Fork end 383
Fork slide 365
Formeret 469, 479
Fornax 19, 20
Fornix 236-237
Fortifications 466
Forum of Trajan 463
Forward bulkhead panel 406
Forward deck 561
Forward defensive stroke 538
Forward dive 558
Forward door 415, 417
Forward-facing eyes 194
Forward fairing 415
Forward-firing machine-gun 405
Forward funnel 393, 395
Forward fuselage structure 401
Forward galley 416
Forward hydroplane 397
Forward main door 412
Forward ramp drive 417
Forward rocker 615
Forward rollover structure 357
Forwards 532, 534-535
Forward short leg 538
Forward spar 415
Fossa ovalis 251
Fossil fuel 280-281, 314-315
Fossilization 278
Fossil record 279
Fossils 278-279
Acanthostega skull 80
Ankylosaurus tail club 95
Birch leaf 74, 76
Blue-green algae 78
Brachiopod 65
Clubmoss 66
Eurypterid 79
Fern 66
Graptolite 65
Horsetail 66
Hyaenodon skull 107
Jawless fish 78
Land plant 64
Lungfish 81
Nautiloid 65
Palm bark 74
Shark teeth 67
Starfish 79
Swamp plant 64
Sweetgum leaf 76
Titanosaurid egg 91
Trilobite 78
Fossil skeleton
Archaeopteryx 85
Bat 105
Parasaurolophus 98
Pareiasaur 81
Struthiomimus 87
Westlothiana 81
Foster, N. 496, 498
Foul lines 536
Fouls 532
Foul tackle 524
Foul tip 537
Foundation
Ancient Roman building 464
Iron paddlesteamer 392
Modern building 496
Nineteenth-century building 492
Foundry plug 387
Fountain pen 444
Four-aspect color light signal 330
Four-chambered heart 104
Four-cylinder 12-HP engine 399
Four-cylinder motorcycle 363
Four-footed dinosaur 88, 92, 96, 100
Four-pulley system 320
Four-stroke combustion engine 366
Four-stroke cycle 343
Fourteenth century 474
Arch 488
Gothic building 471-473
Medieval building 466-467
Roof 490
Style 470
Fourth mast 376
Four-wheel bogie 417
Fovea 224
Fowler flap 413, 414
Foxes 194
Fracastorius 40
Fracture 270
Fractured rock 34
Fragaria x ananassa 128, 150
Fra Mauro 40
Frame
74-gun ship 381
ARV light aircraft 424
Bicycle 358-359
Cannondale SH600
Digital video camera 582
Hybrid bicycle 361
Concert grand piano 515
Concorde, the 416
Harley-Davidson FLHS
Electra Glide 363
Honda VF750 364
Ironclad 393
Longboat 380
Medieval house 466
Modeled sculpture 452
Modern building 496
Motorcycle 364
Oscillating steam engine 390
Racing bicycle 360
Racket 544-545
Relief-printing press 449
Single scull 560
Steam-powered Cugnot 335

Steel 494
Upright piano 514
Weslake Speedway motorcycle 369
Frame angle 360
Frame drum 518
Frame head 340
Frame-mounted fairing 364
Fram Rupes 35
Francis turbine 314
Francium 310
Frapped turn 389
Free nerve ending 235, 239
Freestyle swimming stroke 558
Free-throw line 532-533, 535
Freewheel 361
Freewheel lock nut 358
Freewheel sprocket 360
Freezing 307
Freezing level 302
Freight car 327
Freight service 326
French baroque style 479, 482
French bowline 388
French Flamboyant style 470
French trotter 554
Fresco 434-435
Freshwater bay 291
Freshwater angling 562
Freshwater lake
Lakes and groundwater 292
Weathering and erosion 283
Freshwater turtle 186
Fret 512-513
Fret-pattern mosaic 488-489
Fretwork 461, 491
Frieze
Ancient Egyptian building 459
Ancient Greek building 461
Ancient Roman building 463, 465
Baroque church 479, 481
Cathedral dome 487
French temple 485
Medieval church 469
Neoclassical building 478-479, 482
Renaissance building 476
Twentieth-century building 495
Frigate 396-397
Fring 46-47
Fringed crumble cap 115
Fringilla coelebs 193
Fringing reef 299
Frog 182-183
Double bass bow 511
Eggs 183, 192
Fossil 278
Violin bow 510
Frog kick 559
Frond
Fern 120-121
Seaweed 116-117
Tree fern 112-113
Front air dam 354
Frontal bone
Bony fish 181
Chimpanzee 202
Human 212-213, 220-221
Frontalis muscle 226, 228-229
Frontal lobe 236-237
Frontal notch 213
Frontal process 221
Frontal rib 161
Frontal sinus 212, 245
Front axle
1906 Renault 336-337
Ford Model T 338
Honda VF750 365
Husqvarna Motocross TC610 368
Kirby BSA 369
Front brake cable
Bicycle 359
Eddy Merckx racing bicycle 361
Front brake lever 363
Front bumper 332
Front cantilever brake 359
Front crawl 558-559
Front cylinder exhaust pipe 368
Front derailleur 358-360
Front hazard avoidance camera 615
Front leg 168-169
Front light
Bicycle 360
Paris Metro 328
Italian State Railroads Class 402 328
Frontoparietal bone 183
Frontozygomatic suture 220
Front spring 337
Front wheel
Bicycle 359
Front wing 168
Frost wedging 282, 286-287
Froude's early test propeller 391
Frozen rubber puck 550-551
Fruit
Bramble 130
Couch grass 113
Development 146-147
Dry 150-151
Durmast oak 131
Peach 131
Pitcher plant 113
Rowan 131
Succulent 148-149
Sycamore 131
Fruit wall 148-149, 150-151
Fruticose lichen 114
Fruticose thallus 114
"F" turret 394
Fucoxanthin 116
Fucus spiralis 116
Fucus vesiculosus 116, 117
Fuel/air intake pipe 337
Fuel and oil heat exchanger 418
Fuel and oil tank 398-399
Fuel cap 348, 369
Fuel contents indicator 413
Fuel-cooled oil cooler 419
Fuel drip tray 411
Fuel filler and vent 403
Fuel filler cap
Curtiss biplane 398
Volkswagen Beetle 340
Fuel filler neck 340
Fuel filter 419
Fuel heater 419
Fuel hose 425
Fuel injection 344, 356
Fuel inlet 419
Fuel-jettison pipe 417
Fuel-jettison valve 406
Fuel manifold 418-419
Fuel nozzle 418-419
Fuel pipe
Concorde 417
Curtiss biplane 398
Jaguar V12 345
Fuel reservoir 368
Fuel sediment bowl 339
Fuel shut-off valve cable 419
Fuel sprayer 418
Fuel supply pump 327
Fuel tank
Avro triplane 402
Benz Motorwagen 335
BMW R/60 362
Concorde, the 417
"Deltic" diesel-electric locomotive 326
Harley-Davidson FLHS Electra Glide 363
Helicopter 422-423
Honda VF750 364
Lockheed Electra airliner 407
LVG CVI fighter 405
Pegasus XL SE ultralight 426
Renault Clio 350
Suzuki RGV500 369
Volkswagen Beetle 340
Werner motorcycle 362
Weslake Speedway motorcycle 369
White Steam Car 342
Wright Flyer 398
Fuel tank breather 369
Fuel tank cradle 422
Fuel tank filler cap 369
Fuel tank filler neck 350
Fuel tank filler nozzle 427
Fuel tank sender unit 340
Fuel tank top skin 425
Fuel tap 366
Fuel vent pipe 422
Fulcrum 320-321
Full back
Australian rules football 527
Canadian football 526
Football 526
Gaelic football 529
Rugby 530
Full back line 529
Full-elliptic leaf spring 334-335
Full-elliptic steering spring 337
Full forward 528-529
Fumaroles 272-273
Funaria hygrometrica 119
Funaria sp. 119
Functionalism 496
Function button 585
Function display 520-521
Fundus 258
Fungal filament 114-115
Fungi 112, 114-115, 133
Fungia fungites 167
Fungiform papilla 244
Fungoid-structure encrustations 284
Funicle 150
Funnel
Battleship 395
Frigate 397
Iron paddlesteamer 392-393
Lizard 185
Octopus 176-177
Steamboat with paddle wheels 391
Funnel guide 126
Funnel stay 395
Furcula 189
Furled forecourse sail 375
Furled lateen main sail 376
Furled lateen mizzen sail 375, 376
Furnerius 40
Furrow 282
Furud 21
Fused carpels 140, 144, 151
Fused petals 142, 145
Fused receptacles 149
Fuselage 401, 409, 424, 572, 573
Fuselage bottom skin 424
Fuselage bracing wire 403, 426
Fuselage mid-section 412
Fuselage nose-section 412
Fuselage skin 402
Fuselage spine fairing 414
Fuselage tail-section 415
Fuselage top skin 424
Fuses 591
Fusion crust 52
Futtock shroud 378

G

Gabbro 267, 274
Gable
Gothic building 470-473
Medieval building 467, 469
Nineteenth-century building 492-493
Renaissance building 476
Gabled arch 471
Gacrux 21
Gadolium 311
Gaelic football 528-529
Gaff 380, 385
Gagarin 41
Gait 554
Galactic center 14, 18, 20
Galactic nucleus 12-13
Galactic plane 14-15
Galaxy 10-15, 613
Galena 268
Galeocerdo cuvier 179
Galilean moons 44
Galium aparine 150
Gallbladder
Domestic cat 195
Human 248, 252
Rabbit 196
Tortoise 187
Galle ring 50-51
Gallery
74-gun ship 381
Ancient Roman building 465
Baroque church 479-480
Cathedral dome 487
Frigate 397
Medieval building 466-468
Modern building 496-497
Renaissance theater 477
Wooden sailing ship 378-379
Galley 372-397
Galley area, business class cabin 572, 573
Gallimimus 82, 84, 86-87
Gallium 311
Galois 41
Galvanized "D" shackle 386
Gambrel roof 490
Game target shooting 548
Gamete 154
Brown seaweed 116-117
Bryophyte 118-119
Fern 120-121
Fertilization 146-147
Gymnosperm 122
Moss 112
Pine 122
Vegetative reproduction 154
Yew 123
Gametophyte
Bryophyte 118-119
Fern 120-121
Liverwort 118
Moss 112, 119
Gamma 18, 21
Gamma Centauri 21
Gamma Hydri 20
Gamma Mensae 20
Gamma radiation 10
Gamma ray 22, 318-319
Gamma ring 48
Ganges River 288
Joule 314, 316
Ganges plain 63
Ganges River delta 288
Ganglion 173, 177
Gangway
74-gun ship 380
Colosseum 464
Sailing warship 377
Ganymede 44
Gape
Angling hook 562
Dolphin 204
Garboard strake 393
Gargoyle 473
Garmin Etrex handheld GPS 591
Garnet 267
Garnet-mica schist 267
Garnierite 270
Garudimimus 86
Gas 306-307
Asteroids, comets, and meteoroids 52-53
Chemical reactions 313
Massive stars 26-27
Mineral resources 280-281
NGC 2997 (spiral galaxy) 12
Small stars 24-25
Stellar black hole 29
Gas blanket 300
Gas cloud
Earth's formation 56
Milky Way 14
Nebulae and star clusters 16-17
Origin and expansion of universe 10-11
Gas current 29
Gas deposit 57, 281
Gaseous exchange in alveolus 255
Gaseous water 49
Gas exchange 134
Leaf 138-139
Photosynthesis process 138
Root 132
Sunken stoma 156-157
Wetland plants 158
Gas formation 280-281
Gas giants
Jupiter 44-45
Neptune 50-51
Saturn 46-47
Solar system 30-31
Uranus 48-49
Gaskin 198, 554
Gas loop 32-33
Gas molecule 53
Gassendi 40
Gas shell 16-17, 25
Gas tail 52-53
Gastralia 85, 87
Gas traps 281
Gastric artery 253
Gastrocnemius muscle
Albertosaurus 84
Euoplocephalus 94
Human 226-227
Iguanodon 97
Gastroepiploic vein 253
Gastropod mollusk 75
Gastropods 176, 279
Gastrovascular cavity 167
Gas turbine 418
Gate
Building 467, 490-491
Canoeing 560
Downhill skiing 552
Hydroelectric power station 314
Gate clamp 560
Gate-house 467
Gateway 460
Gatwick Express "People Mover" 328
Gauge 330-331
Gauge class 325
Gauged arch 492
Gauntlet 540, 557
Gavialis gangeticus 186
G clef 502
Gear band 336
Gearbox
ARV light aircraft 425
Ford Model T 339
Harley-Davidson FLHS Electra Glide 363
Motorcycle 364, 366
Renault Clio 351
Volkswagen Beetle 340
Wind turbine 605
Gearbox bevel drive 418
Gearbox case 410
Gearbox drive spline 410
Gearbox fixing stud 356
Gearbox mount 413
Gearbox oil scavenge line 419
Gearbox unit 413
Gear cable 359
Gearcase 601
Gearcase position 600
Gear change 363
Gear-change rod 351
Gear lever
1906 Renault 337
Husqvarna Motocross TC610 368
Renault Clio 350
Two-stroke engine 366
Gear lever knob 340
Gear lever surround 352
Gear ratios 361
Gear retainer 562
Gear shift 359
Gear system 358, 366
Gears
Drills 600
Motorcycle 366
Gelatine roller 447
Gemini 18
Gemma 118
Generative nucleus 147
Generator 317
British Rail class 20 diesel engine 327
Diesel train 326
Electric train 326
Nuclear power station 314
Van de Graaff 316
Wind turbine 605
Generator cooling fan 327
Generator housing 411
Generator rotor
Hydroelectric power station 314
Mid West engine 410
Generator unit 314
Genetic material 606, 607
Genioglossus muscle 245
Geniohyoid muscle 245
Genome 607
Genital plate 175
Gentlemen's room 477
Geographic pole 38
Geological time 56-57, 279
Geranium pratense 144
Gerberette 497
Gerbil 196
Germanium 311
German-style baroque 482
Germany 326
Germinal epithelium 258

Germination 152-153
Cabbage seed 132
Epigeal 152-153
Fern spore 121
Hypogeal 152-153
Mushroom spore 115
Pine 122
Pollen grain 146-147
Gesso 432, 453
Get mail button 576
Geyser 272-273, 275
Gharial 186
Ghost anemone 166
Giant redwood 112
Giant slalom 552
Giant stars 22-23, 26
Gibbon 202
Gibson Les Paul guitar 513
Gig 395
Gilded band 490
Gilded cross 487
Gilded orb 487
Gilded rib 487
Gilded truck 378-379
Gilding materials 431, 432
Gill
Bivalves 176
Bony fish 180-181
Dogfish 178-179
Fungi 114-115
Lamprey 178
Newt 182
Salamander 182
Tadpole 183
Gill filament 180
Gill opening 178
Gill raker 180
Gill slit 178-180
Gilt ironwork 482, 490
Ginger 155
Gingiva 247
Ginkgo 68, 70, 72, 122-123, 279
Ginkgo biloba 68, 123
Ginkgophyta 122
Ginkgo pluripartita 72
Giornate 434-435
Giraffa camelopardalis 199
Giraffe 198-199
Girder 493
Girdle 116
Girdle scar 123
Girth
Harness racer 555
Showjumper 554
Gizzard
Bird 189
Brachiosaurus 91
Euoplocephalus 94
Gallimimus 86
Glabella
Human skull 213, 221
Trilobite fossil 78
Glacial deposits 286-287, 292-293
Glacial periods 56-57, 76
Glacial sediments 299
Glacial streams 286
Glacier Bay 286
Glacier features 286-287
Glaciers 286-287
Prehistoric Earth 66, 76
River's stages 289
Rock cycle 266-267
Weathering and erosion 282
Glacier snout 286, 289
Gladiolus 154-155
Gland
19th century paddlesteamer 391
Axial 175
Butterwort 161
Cement 173
Green 173
Monkey cup 161
Mucous 177
Pedal 177
Poison 170, 176
Rectal 179
Salivary 177
Silk 170
Venus fly trap 160
Glans penis 259
GLARE upper fuselage 572
Glass 307
Buildings 492, 494
Photovoltaic cell 605
Tesserae 450
Glass bulb 319
Glass cooking turntable 596
Glass curtain 497
Glass deflector 325
Glass enamel 450
Glass flask 312
Glass mosaic 489
Glass muller 436, 440
Glass pane 494
Glass paper 441
Glass plate 570, 571
Glass prism 318
Glass slab 436, 440
Glass tube 319
Glass wall 496, 499
Glazing
Acrylic paints 442
Modern building 496-499
Twentieth-century building 494
Glazing bar 499
Gleba 114-115
Glechoma hederacea 154
Gleditsia triacanthos 137
Glenoid cavity 80
Gliders 426-427
Global positioning system (GPS) 590-591
Global warming 301
Globe 264
Globe Theater 477
Globular cluster 12, 16, 21
Globule 24, 26
Glomerulus 256-257
Gloriosa superba 143
Glory lily 143
Gloss finish
Acrylics 442
Oil painting 436
Glossopteris 67
Gloster Meteor fighter 408
Glove box 425
Gloves
Baseball fielder 537
Cricket batsman 539
Cricket wicket-keeper 539
Fencing 556-557
Football 527
Ice hockey 551
Lacrosse goalkeeper 541
Racketball 545
Sailing 560
Skiing 552-553
Soccer goalkeeper 525
Glucose 138
Glulam wall-plate 499
Gluon 309
Gluteal fold 210
Gluteus maximus muscle 227
Gluteus medius muscle 225
Gluteus minimus muscle 225
Glyph 460
Gnathostomata 178, 180
Gneiss 274
Gnetophytes 122

Gnome seven-cylinder rotary engine 400
Gnomon 377
Goal
Australian rules football 528
Gaelic football 529
Hockey 540
Hurling 541
Ice hockey 550
Lacrosse 541
Rugby 530-531
Soccer 524
Goal area
Gaelic football 529
Handball 535
Soccer 524
Goal attack 535
Goal circle 535, 541
Goal crease 541, 550
Goal defense 535
Goal judge 550
Goalkeeper
Australian rules football 528
Gaelic football 529
Handball 534-535
Hockey 540
Ice hockey 550
Lacrosse 541
Netball 535
Soccer 524-525
Goalkeeper's equipment 540
Goalkeeper's gloves 525
Goalkeeper's helmet 550-551
Goalkeeper's kicker 540
Goalkeeper's pad 550
Goalkeeper's shirt 525, 550
Goalkeeper's stick 550
Goal line
Australian rules football 528
Football 526
Handball 535
Hockey 540
Ice hockey 550
Rugby 530
Soccer 524
Goal line referee 535
Goal net 524, 534, 550
Goalposts
Australian rules football 528
Football 526
Gaelic football 529
Netball 535
Rugby 530
Goal shooter 535
Goal square 528
Goal third 535
Goal umpire 528-529
Goat 198
Goat hair brush 438, 442
Calligraphy 444
Goat hake wash brush 438
Gobi Desert 265
Goggles
Harness racing 555
Skiing 552-553
Swimming 558
Gold 31, 268, 280-281, 438
Gold chalcopyrite 271
Golden barrel cactus 156
Golden lion tamarin 203
Gold leaf 432
Fresco 435
Illumination 444-445
Smalti 450
Vitreous glass 451
Wood sculpture highlighting 453
Golf 546-547
Golgi complex 217
Gomphoi 373
Gonad
Jellyfish 167
Octopus 176
Sea anemone 167
Sea urchin 175
Starfish 174
Gondwana
Cretaceous period 72
Jurassic period 70-71
Late Carboniferous period 66-67
Middle Ordovician period 64-65
Gong 504, 516
Goniastrea aspera 167
Gonopore
Barnacle 173
Sea urchin 175
Snail 177
Starfish 174
Goose-feather quill 444
Goosegrass 150
Goose neck 388
Gopher 196
Gopuram finial 491
Gorge
Cave 284-285
River features 290
Gorilla 202-203
Gothic architecture 468, 470-473
Gothic book script lettering 445
Gothic stone arch 467
Gothic torus 470
Gouge
Relief printing 446, 449
Woodcarving 454-453
Gour 284-285
Goya 35
GPS 590-591
Grab handle 362
Graben 61
Graben lake 293
Gracilis muscle 226-227
Graded wash 439
Graffian follicle 258
Graffias 21
Gran Chaco 264
Grand Canyon 57, 226-227
Grand piano 514-515
"Grand Prix" world championships 368
Grandstand 555
Granite-aggregate slab 499
Granite cladding 494
Granular stalk 114
Granum 139
Grape hyacinth 155
Graphics card 567
Graphite 268, 311
Graphite pencil 430
Graphite stick 430
Grapnel-type anchor 376
Grasping tail 202
Grass 113
Grate 324
Grating 380-381
Graver 449
Gravitation (gravity)
Atmosphere 300
Force and motion 320
Neutron stars and black holes 28
Oceans and seas 296-297
Universe 10
Gravitational pull 296-297
Gravity-feed fuel tank 405
Gray Cliffs 276
Gray matter 236-237, 238
Gray squirrel 197
Gray whale 204
Grease 446
Greaser 339
Great Bear Lake 264
Great cabin 379, 381
Great Dark Spot 50-51
Greater blackbacked gull 193
Greater flamingo 190
Greater omentum 214
Greater palatine foramen 220
Greater trochanter of femur 224-225
Greater wing coverts 188
Greater wing of sphenoid bone 220-221
Great Lakes 264
Great manual 514
Great Mosque 484
Great Red Spot 44-45
Great Rift Valley 60
Great saphenous vein 253
Great stop 514
Greek ship 372-373
Greek-style fret ornament 483
Green (golf) 547
Green alga 112, 116-117
Green calc-silicate mineral 275
Green cell 584
Green chlorophyll pigment 116, 138
Gorilla 202-203
Green earth 434-435
Green fluorite 269
Green gland 173
Greenhouse effect 36, 300-301
"Greenhouse gas" 301
Greenland
Cretaceous period 73
Late Carboniferous period 66
Middle Ordovician period 64
Satellite map 264
Green light 318, 330-331
Green seaweed 117
Green snakelock anemone 166
Green starboard navigation light 406
Greenwich Meridian
Satellite map 264-265
Surface currents 296
Gregorian calendar 681
Grid lines 445
Griffon 461
Grikes 284
Grille
"Eurostar" warning horn 329
Roman Mill 464
Grill/griddle 596
Grimaldi 40
Grip
Sailmaker's fid 384
Sailmaker's mallet 384
Gripe 379
Groin
Arches and vaults 485
Human body 211
Groin pad 527
Groin vault 479, 484-485
Grommet 373, 375, 384, 426
Groove
Rope starter 335
Serving mallet 384
Grooved racing tire 356, 357
Groove for FCC cable 571
Grooving 383
Grotesque figure 476
Ground handling wheel 422
Ground ivy 154
Ground-mapping radar 420
Groundmass 268-269
Ground roller 447
Groundwater 292-293
Volcanic structure 273
Grout 450-451
Growing point 153
Growing tip 79
Growth line
Fossilized jawless fish 78
Snail 177
Groyne 294
Grundtvig Church 495
Gruppo Seven Cubist 495
Grus 19, 20
Gryphon 461
Gryposaurus 96, 99
Guanine 216
Guard
Basketball 532
Fencing foil 557
Football 526
Guard cell 138-139
Guardrail 391-392, 395
Guardstop 541
Gubernator 373
Gudgeon 375
Gudgeon pin 345
Gudgeon strap 378
Guest boat boom 394
Guiana Highlands 264
Guidance control sensor 612
Guide hair 126
Guide mark 535
Guide wheel 328
Guinevere Planitia 36, 37
Guitars 510, 512-513
Gula Mons 37
Gulf of Mexico 264
Gulf Stream 296
Gull 189, 193
Gulley 538
Gully 289
Gum 247
Gum arabic 438
Lithographic printing 446, 448
Pastel making 440
Gun
1.3 kg gun 395
3 pound gun 395
4½ in gun 397
4¾ in gun 394
11 cm gun 397
12 cm gun 394
12 in gun 394
30 cm gun 394
Battleship 394
Frigate 397
Measurements 394
Sailing warship 376
Wooden sailing ship 378, 379
Gun battery 395
Gun carriage 377
Gun deck 380
Gun loading cage 396
Gunnery control radar dish 397
Gunnery spotting top 394
Gunport 381
Sailing warship 376-377
Wooden sailing ship 379
Gun position 397
Gun section 392
Gunship 422
Gun turret 396-397
Battleship 394
Frigate 397
World War II aircraft 408
Gut cecum 170
Gutenberg discontinuity 39
Gutter 486, 492, 602
Guyot 298
Guzmania lingulata 162-163
Gymnosperm 122-125
Gynoecium 140
Gypsum 271
Gyroscopic gunsight 409

H

Habit 270-271
Habitat 112
  Dryland plants 156-157
  Wetland plants 158-159
Hackle 563
Hackly fracture 270
Hadar 21
Hadley cell 300
Hadrosaur 96, 98-99
Hadrosaurus 96, 99
Hafnium 310
Hagfish 178
Hail 302
Hair 234-235
  Cobra lily 160
  Golden barrel cactus 156
  Inflorescence 140, 142
  Insulating 104, 107
  Mammal 104
  Marram grass 113
  Monocotyledon 126
  Pitcher plant 113
  Root 132
  Venus fly trap 160
  Water fern leaf 158
Hair bulb 235
Hair cell 242-243
Hairdryer 315
Hair follicle 234-235
Hair gel 306
Hair-like sepal 142
Hair shaft 235
Hakatai shale 277
Hale-Bopp Comet 53
Halfback 526, 529
Halfback flank 528
Half-column 464, 468-469
Half-court line 545
Half-forward 529
Half-forward flank 528
Half-fruit 151
Half hitch 388
Half-shaft
  Ford Model T 338
  Formula One race car 356
  Half turn 543
Halide 269
Halite crystal 277
Hall
  Asian building 491
  Hypostyle 458
  Medieval building 466-467
  Modern building 496, 499
  Neoclassical building 483
Halleflinta 275
Halley's Comet 52
"Hall-keeps" 466
Hallux
  Anchisaurus 89
  Archaeopteryx 85
  Herrerasaurus 86
  Human 232
  Tyrannosaurus 84
Halo 14
Halogen headlight bulb 352
Halogens 311
Halo ring 44
Halyard
  Double topsail schooner 385
  Junk 376
  Longboat 380
  Rigging 382
  Roman corbita 372, 373
  Viking karv 374
Hamada 282-283
Hamal 19, 20
Hamate bone 230
Hammer 242, 285
  Antler 109
  Athletics 542
  Concert grand piano 515
  Mosaic 450
  Target pistol 549
  Upright piano 514
Hammer actuator 600-601
Hammer-beam roof 470, 473
Hammerhead shark 179
Hammer throw 543
Hand
  Anchisaurus 89
  Human 210
  Iguanodon 97
  Pachycephalosaurus 100
  Primate 203
  Stegoceras 101
  Tyrannosaurus 84
Handball 534-535
Handbrake 337, 339-340, 350
Handbrake control shaft 338
Handbrake quadrant 339
Hand brake wheel 331
Hand drill 600-601
Handheld gun 408
Handle
  Belaying pin 382
  Brace-and-bit 601
  Steam iron 594
Handlebars
  Bicycle 358-359
  BMW R /60 362
  Cannondale SH600 hybrid bicycle 361
  Cannondale ST 1000 touring bicycle 361
  Eddy Merckx racing bicycle 361
  Suzuki RGV500 368
Handle connector 593
Handling
  Motorcycle 360
  Touring bicycle 364
Hand protector 368
Hand rail
  "Ellerman Lines" steam locomotive 524
  Modern building 498
  Renaissance building 477
  Sailmaker's mallet 384
  Serving mallet 384, 388
  Ship's wheel 390
  TGV electric high-speed train 329
  Twentieth-century building 194
Hands 230-231
Handstand 543
Hand throttle 427
Handy Billy 382-383
"Handy man" 108
Hanger 498
Hang-gliders 426-427
Hanging valley 286-287
Hapteron 116-117
Hard disk drive 567
Hard endocarp 146-147, 149
Hard granite 283
Hard hat 554
Hard-headed beater 516, 518-519
Hard metals 310
Hardness 270-271
Hard palate 212, 245
Hard rock 60
  Faults and folds 60
  Glacier 286
  River features 290-291
  Weathering and erosion 282
Hard trim 352
Hardwood implements 452
Hardwood laminate limb 548
Hardwood panels 432
Hardwood sticks 517
Hardy 450
Hare 196-197
Harley-Davidson FLHS Electra Glide 362-363
Harmika 491
Harmon, A.L. 494
Harmonically-tuned exhaust system 356
Harmony
  Drums 518
  Percussion instruments 516
Harness
  Avro triplane IV 402
  Equestrian sports 555
Harness racing 554
Harness strap 409
Harp 504, 510-511
Harpoon point 109
Hash mark 541
Hastate leaf 128
Hatch
  Cargo 376
  For home deliveries 602
  Iron paddlesteamer 393
  Single scull 561
Hatch board 372
Hatch coaming 381
Hatching egg 192-193
Hatchling 98
Hathor Mons 37
Haunch 484
Haustoria 163
Haustration of colon 249
Haversian system 225
Hawker Tempest 408-409
Hawksmoor, N. 478, 481
Haworthia truncata 157
Hawse hole
  74-gun ship 381
  Sailing warship 376
  Wooden sailing ship 378
Hawse piece 381
Hawse pipe 393, 395
Hawser 386-387
Hawser fairlead 395
Hawthorne 35
Haystack boiler 334
Haze 37, 47
Head
  74-gun ship 380
  Allosaurus 85
  Beetle 168
  Brace-and-bit 601
  Bumblebee 168
  Butterfly 169
  Caterpillar 169
  Ceratopsian 100
  Deer hopper dry fly 563
  Double bass bow 511
  Double topsail schooner 385
  Dunkeld wet fly 563
  Femur 224-225
  Frog 182
  Hammer 542
  Human 211, 212-213
  Insect 168
  Lacrosse crosse 541
  Lamprey 178
  Pachycephalosaurus 100
  Phalanx 230
  Prosauropod 88
  Racing bicycle 360
  Racing saddle 554
  Rattlesnake 185
  Sail 375, 384
  Sauropodomorph 88
  Serving mallet 388
  Snail 177
  Sperm 259
  Stegoceras 101
  Stegosaurus 92
  Tennis racket 544
  Thyreophoran 92
  Ulna 231
  Violin bow 510
Headband 544
Head beam 380
Headboard 381
Head-butting contest 100
Head crest 96
Head cringle 384
Head data cable 574
Head data cable support 574
Head earing 375
Headers
  Brickwork 485
  Nineteenth-century building 492
Head horn 94
Head joint 508
Headlight
  Bordino Steam Carriage 335
  Bulbs 352
  Ford Model T 338-339
  Renault Clio 349, 353
  Volkswagen Beetle 341
Headland 294
Headlight
  BMW R/60 362
  "Eurostar" multi-voltage electric train 329
  Harley-Davidson FLHS Electra Glide 363
  Italian State Railroads Class 402 328
  MCW Metrobus 332
  Single-decker bus 333
  "Union Pacific" locomotive 326
  Vespa Grand Sport 160
  Mark 1 363
Head linesman 526
Headphone jack 578, 586, 587
Head rail 380-381
Headrest
  Airbus 380 273
  ARV light aircraft 425
  Formula One race car 356
  Hawker Tempest fighter 409
  Mazda RX-7 346
  Renault Clio 349, 352
  TGV electric high-speed train 329
  "Windcheetah" racing
  HPV bicycle 361
Head rope 387
Headset 361
Headstock
  Acoustic guitar 512-513
  Electric guitar 513
  Honda VF750 364
Head tube 359-361
Headward erosion 290
Headwaters 288
Hearing 237, 242
Heart
  Bird 189
  Bony fish 181
  Branchial 176
  Butterfly 169
  Chimpanzee 202
  Crayfish 173
  Dogfish 179
  Dolphin 205
  Domestic cat 195
  Elephant 200
  Euoplocephalus 94
  Frog 182
  Gallimimus 86
  Human 214-215, 250-251
  Lizard 185
  Mammal 104
  Octopus 176
  Rabbit 196
  Snail 177
  Spider 170
  Systemic 176
  Tortoise 187
Heartbeat sequence 250-251
Heart bulge 260
Heartwood 125
Heat 314-315
  Chemical reactions 312
  Global warming 300-301
  Igneous and metamorphic rocks 274
Heat absorption 92
Heated filament 319
Heater element contacts 348
Heater unit 353
Heat exchanger
  Concorde 417
  Nuclear power station 314
  Volkswagen Beetle 340
Heat exchanger air intake 421
Heat exchanger exhaust duct 420
Heat exchanger hot-air exhaust 421
Heating element cover 597
Heating elements 594
Heating element terminal cover 597
Heat radiation 92
Heat shield
  Jet engine 419
  Motorcycle 363
  Space probes 614
Heat trapping 300
Heaver for wire serving 385
Heaving line 389
Heavy chemical elements 27
Hedera colchica 137
Hedera helix 131, 137
Heel
  Horse 198
  Human 210
  Rudder post 392
Heel molding 594
Heine 35
Heka 18
Helen Planilia 36
Helianthus annulus 142
Heliconia peruviana 143
Helicoprion bessonowi 67
Helicopter landing-pad 498
Helicopters 396, 410, 422-423
Helium
  Jupiter 44-45
  Massive stars 26
  Mercury's atmosphere 35
  Neptune's atmosphere 51
  Pluto's atmosphere 51
  Periodic table 311
  Saturn 46-47
  Small stars 24-25
  Sun 32
  Uranus' atmosphere 49
Helium-3 nucleus 22
Helium-4 nucleus 22
Helium line 23
Helium tank 614
Helix 242, 623
Helix Nebula 17
Helleborus niger 139
Hellenic plate 59
Helmet
  Baseball batter 536
  Bicycle 360
  Cricket 539
  Football 526-527
  Hockey goal keeper 540
  Hurling 541
  Ice hockey 550-551
  Lacrosse goalkeeper 541
  Skiing 542
Helmsman 372-373
Hemal spine 180
Hematite 268
Hemicyclapsis 56
Hemisphere 623
Hemispherical dome 477, 486-487, 490-491
Hen coop 395
Hepaticae 118
Hepatic artery 248, 252-253
Hepatic portal vein 253
Heptathlon 542
Heracleum sp. 151
Heracleum sphondylium 129
Heraldic device 372
Herbaceous plants 126, 128-129
  Structure 112-113
  Woody 130-131
Herbaceous stems 134
Herbivores
  Carnivora 194
  Jurassic period 70
  Marginocephalian 100
  Ornithopodian 96
  Prosauropods 88-89
  Sauropodomorphian 88
  Triassic period 68
Hercules 19, 20, 40
Herds 88
Hermaphrodite duct 177
Hermit shale 276
Herodotus 40
Herrerasaurids 68, 86
Herring-bone pattern 488
Hertzsprung 41
Hertzsprung-Russell diagram 22-23
Hesperidium 148
Hestia Rupes 37
Heterocentrotus mammillatus 175
Heterodontosaurus 83
Heteropoda venatoria 171
Hexagon 622
Hexagonal system 270
HF radio aerial 408
HF radio aerials fairing 417
Hibiscus 126-127
Hide 105
Hide grip 384
Hieroglyphs 458-459
High altar 470
High-altitude cloud 45, 50
Highboard diving 558
High-density minerals 280
High-energy particle 301
High-energy radiation 22
High-explosive projectile 396
High-gain antenna 615
High-gain radio antenna 612, 613
High-jump 542
Highland coastline 295
High-level jet streams 300
High nose 357
High-performance microscopes 610-611
High-pressure areas 302-303
High-pressure bleed venturi connector 419
High-pressure compressor 418
High-pressure cylinder 342
High-pressure turbine 418

High-pressure zone 300
High-speed trains 328-329
High Spring tide 296-297
High temperature gas 306
High-tension beam 496
High-tension ignition lead 344
High tension wire 315
High tide 296-297
High-velocity air duct 420
High voltage cable 314, 355
High-voltage connector 355
High-voltage magnetron supply 596
Hi-hat cymbal 518
Hilbert 41
Hillman anti-kink weight 562
Hilum
  Dehiscent fruit seed 151
  Epigeal germination 153
  Hypogeal germination 152
  Succulent fruit seed 148-149
Himalayas
  Earth's physical features 264-265
  Geological time 56-57
  Formation 60, 62-62
  Mountain building 62-63
  Quaternary period 77
  Tertiary period 74
Himeji Castle 490
Hind foot
  Caiman 187
  Stegosaurus 92
Hindgut 173
Hind leg
  Amphibian 182
  Beetle 168
  Bumblebee 168
  Butterfly 169
  Caiman 187
  Elephant 200
  Frog 182
  Hare 196
  Iguanodon 97
  Lizard 185
  Rabbit 196
  Terrapin 187
Hind limb
  Anchisaurus 89
  Corythosaurus 98
  Edmontonia 95
  Frog 182
  Iguanodon 96
  Kangaroo 207
  Pachycephalosaurus 100
  Prosauropod 88
  Psittacosaurus 103
  Rabbit 197
  Rat 196
  Salamander 182
  Stegoceras 101
  Stegosaurus 92
  Theropods 84
  Thyreophoran 92
  Triceratops 102
  Tyrannosaurus 84
Hindlimb bone 105
Hind wing 168-169
  ARV light aircraft 425
  BAe-146 components 412-415
Hinge 571
Hinge bracket 414
Hinge cell 113, 160
Hinged bin/cyclone cover 593
Hingeless bivalve shell 79
Hingeline 60
Hip
  Anchisaurus 89
  Human 211
  Kangaroo 207
  Lion 195
  Midway Gardens 495
  Stegosaurus 92
Hip girdle 80
Hip joint 218, 224-225
  Brachiosaurus 90
  Diplodocus 90
  Gallimimus 86
  Parasaurolophus 98
  Plateosaurus 88
  Stegoceras 101
  Struthioinimus 87
Hip pad 527
Hippeastrum sp. 155
Hipped roof 476-477
Hippocampus kuda 180
Hippophae rhamnoides 136
Hippopotamus 198
Hippopotamus amphibus 77
Hippuris vulgaris 135
Hip-rafter 490
Hispano Mark V 20-mm cannon 409
Historiated boss 469
Historiated keystone 469
Hitachi S-3500H scanning electron microscope 611
Hitched hauling end 383
Hitch-kick 543
Hitch pin
  Concert grand piano 515
  Upright piano 514
Hittorff, J.I. 479
Hobbles 554
Hock 195, 198
Hockey 540-541
Hock joint 554
Hog hair brush 432, 434
Hog's-back 283
Hog's back jump 554
Hogweed 129, 150-151
Hohenbuehelia petaloides 115
Hoisting cage 396
Holden 43
Holdfast 116-117
Holding 527
Holding timekeeper 556
Hold pillar 393
Hole and peg joint 373
Hollow disk wheel 361
Hollow pith cavity 120
Holmium 311
Holocene epoch
  Fossil record 279
  Geological timescale 57
Holostean fish 73
Homarus sp. 73
Home cinema 584-585
Home key 578
Homeosaurus pulchellus 71
Home page 577
Home plate 536
Home run 536
"Home" signal 330
Hominid 74-75, 108-109, 202
Homocephale 101
Homo erectus 108
Homo habilis 108
Homo sapiens 57, 76, 108-109
Honda CB750 362-363
Honda Insight 354
Honda VF750 364-365
Hone-stone 452
Honesty 150-151
Honeycomb coral 167
Honey guides 140-141, 145
Honey locust 137
Hong Kong and Shanghai Bank 496, 498
Honshu 265
Hood
  1906 Renault 337
  Battleship 394
  Ford Model T 339
  Gun turret 396
  Jellyfish 167
  Pitcher plant 160
  Renault Clio 349
  Volkswagen Beetle 340-341
Hood bag 346
Hood catch 336, 349
Hood end 374
Hood frame 339
Hood iron 334
Hood-mold 479, 481, 486
Hood-release cable 349
Hood-release handle 341
Hoof 198, 554
Hoofbone 105, 198
Hooflike nail 36-37
Hook
  Angling 562
  Cricket 538
  Deer hopper dry fly 563
  Devon minnow 563
  Rigging 383
  Sail 384
Hooked beak 190
Hooked pericarps 150
Hooked riffler 454
Hooker 530
Hoop 380, 425
Hoover Factory 495
Hop 543
Hopper freight car 327
Horizon 576
Horizontal bed rock 61
Horizontal cleavage 270
Horizontal muffler 329
Horizontal fissure 255
Horizontally opposed engine 362
Horizontal movement 60
Horizontal, stabilizer 423
Horizontal tailplane 572
Horn
  Ford Model T 339
  Glacier 286-287
  Mooring 387
  Musical instrument 503, 504
  "Union Pacific" locomotive 326
  Vespa Grand Sport 160
  Mark 1 363
Horn balance 414, 415
Horn bulb 339
"Horned faces" 100
Horny beak 96
Horse 104-105, 198-199
Horse chestnut 150, 137
Horse-drawn vehicle 532
Horsehair bow 510-511
Horsehead Nebula 16
Horse riding 554-555
Horseshoe arch 484
Horsetail 120-121
Horsley Church 473
Horst 61
Horu Geyser 272
Hose base 593
Hose cuff electrical link 593
Hose electricity supply connector 592
Hose slider 592
Hose slider seating 592
Host plants 162-163
Hot-air de-icing duct 414
Hot mineral springs 272
Hot spot
  Black holes 29
  Earth's crust 58
  Ocean floor 298
Hot water jet 273
Hound 378
Hour line 377
Household appliances 315
House of the future 602-603
Housing
  Alpine skiing 552
  Electric motor 342
House spider 171
Howe 36
Howea forsteriana 126
Howler monkey 202
HP Pavilion DV4 laptop 566
Hti 490
Huang He 265
Huayangosaurus 93
Hub
  1906 Renault 336
  ARV light aircraft 424
  Benz Motorwagen 335
  Bicycle wheels 358-359
  Blackburn monoplane 400-401
  Bordino Steam Carriage 334
  Eddy Merckx racing bicycle 361
  Paddle wheel 390-391
  Pegasus Quasar ultralight 427
  Propellers 390
  Renault Clio 351
  Wright Flyer 399
Hub and brake drum 350
Hub bearing 351
Hubble Space Telescope 612-613
Hub bolt 338
Hub brake shoe 338
Hub cap
  1906 Renault 336
  Ford Model T 339
  Renault Clio 350
Hub carrier 351
Hub controller 604
Hub nut 350
Hub quick release lever 361
Hub seal 350
Hudson Bay 264
Hull
  Carvel-built 376, 391
  Clinker-built 375
  Cross-section 378
  Double-ended 375
  Greek and Roman ships 372-373
  Iron and wood 392
Hull plank 373
Human body 210-211
Human classification 108
Human Powered Vehicles (HPV) 358, 360
Humans 57, 76, 108, 202, 315
Humber engine 343
Humboldt current 296
Humerus
  Archaeopteryx 85
  Arsinoitherium 104
  Bird 189, 191
  Brachiosaurus 91
  Crocodile 186
  Diplodocus 90
  Domestic cat 195
  Elephant 201
  Eryops 80
  Euoplocephalus 94
  Frog 185
  Gallimimus 86
  Hare 197
  Horse 199
  Human 218
  Iguanodon 96
  Kangaroo 206
  Kentrosaurus 93
  Pareiasaur 81
  Plateosaurus 88
  Stegoceras 100
  Struthiomimus 87
  Toxodon 106
  Triceratops 102
  Tyrannosaurus 84
Humic acid 284
Hunter-killer submarine 396-397
Hunter's bend 388
Hunting 108, 548
Huntsman spider 171
Hurdle races 554
Hurdling 542
Hurling 540-541
Hurricane 302-303
Husk 150
Husqvarna Motocross TC610 368
Huygens mini-probe 614
Hyaenodon 74, 107
Hyaline cartilage 225
Hybrid bicycle 360-361
Hybrid car 354
Hybrid power 355
Hydra 18, 21
Hydrated copper sulfate 313
Hydraulic actuator attachment 413, 414
Hydraulic brake calliper 424
Hydraulic brake hose 369
Hydraulic brake pipe 414
Hydraulic fluid
  Disc brake 365
  Spring/muffler unit 365
Hydraulic grab 396
Hydraulic hand-pump 421
Hydraulic hose 369
Hydraulic unit 605
Hydrocarbon 313
Hydrochloric acid 312
Hydrochoerus hydrochaeris 197
Hydroelectric power-station 314
Hydrogen 308, 310
  Candle wax 312-313
  Covalent bonding 309
  Jupiter's atmosphere 45
  Massive stars 26
  Mercury's atmosphere 35
  Nebulae and star clusters 16-17
  Neptune's atmosphere 51
  Nuclear fusion in Sun 22
  Salt formation 312
  Saturn's atmosphere 47
  Small stars 24-25
  Sun 32
  Uranus' atmosphere 49
Hydrogen alpha line 23
Hydrogen atom 138, 596
Hydrogen beta line 23
Hydrogen fluoride 308
Hydrogen gamma line 25
Hydrogen gas 312
Hydrogen nucleus 22
Hydrogen requirement 138
Hydrogen sulfide 51
Hydroplane 396-397
Hydroxide 268
Hydrus 20
Hyena 194
Hymenoptera 168
Hyoglossus muscle 244
Hyoid bone 244-245, 255
Hypacrosaurus 99
Hypaethral temple 460-461
Hyperesion 373
Hyperlink 577
Hyphae
  Fungus 114-115
  Mycorrhizal association 133
Hypocotyl 152-153
Hypodermis
  Gynosperm 125
  Human 235
Hypogeal germination 152-153
Hypoglossal nerve 244
Hypogymnia physodes 114
Hypostyle hall 458-459
Hypothalamus 236
Hypsilophodon 72, 82
Hypural 180
Hystrix africaeaustralis 197

I

I bar 393
IBM-compatible PCs 566
Ice 66, 307
  Glacier 286-287
  Weathering and erosion 282
Ice age 56
Ice-age mammals 76
Ice block
  Ice-fall 287
  Lake formation 293
Ice cap 287
Ice crystal 302
Ice cube 307
Ice erosion 287
Ice-fall 287
Ice hockey 550-551
Ice margin lake 286
Ice-plant 128-129
Ice sheet 76
Ichthyosaur 70-71
Ichthyostega 56, 80
Icons 576
Icterus galbula 193
Idle control valve 344
Idocrase 270
Igneous intrusion 274
Igneous rock 266-267, 274-275
Igniter 418
Igniter plug 419
Ignition amplifier 345
Ignition coils 354
Ignition control 362
Ignition lever 338
Ignition lock 362
Ignition switch 337
Ignition trigger housing 410
Iguana iguana 82
Iguanodon 73, 96-97
Ileocaecal fold 249
Ileum
  Bird 189
  Frog 182
  Human 226, 249
  Rabbit 196
Iliac crest 224-225
Iliac fossa 224
Iliac spine 224
Iliacus muscle 225
Ilio-femoral muscle 84, 97
Ilio-fibular muscle 84, 97
Ilio-ischial joint 82
Iliopsoas muscle 226
Ilio-pubic joint 82
Ilio-tibial muscle
  Albertosaurus 84
  Euoplocephalus 94
  Iguanodon 97
Ilium
  Archaeoptetyx 85
  Bird 189
  Diplodocus 90
  Eryops 81
  Euoplocephalus 94

Frog 183
Gallimimus 86
Human 218
Iguanodon 96-97
Kentrosaurus 93
Ornithischian 82
Parasaurolophus 98
Plateosaurus 88
Saurischian 82
Stegoceras 100-101
Stegosaurus 93
Struthiomimus 87
Toxodon 107
Tuojiangosaurus 93
Tyrannosaurus 84
Illuminated manuscript 432
Illumination 444-445
iMac 566
Image controls 611
Imaging system housing 610
Imaging the body 214
Imago 168
Immature pitcher 161
Immature spur 141
Impasto 436-437, 442
Impeller 347
Imperial-Metric conversions 591, 620
Imperial unit measurements 590
Impermeable clay 292
Impermeable mudstone 292
Impermeable rock
Cave 284-285
Lake 292
Mineral resources 280-281
River's stages 289
Impermeable salt dome 281
Impermeable shale 292
Impost
Ancient Roman building 465
Cathedral dome 484
Gothic building 473
Islamic building 488
Medieval building 466, 469
In-board 561
Inboard elevon 417, 421
Inboard elevon-jack fairing 416
Inboard end 387
Inboard engine 415
Inboard lift spoilers 413
Inboard trimtab 413
Inbound line 526
Inbox folder 576
Incandescent light 318-319
In-car GPS 590-591
In-car mounting bracket assembly 590
In-camera memory chip 580
Incident laser light 319
Incisive canal 245
Incisor teeth
Bear 194
Chimpanzee 202
Elephant 201
Human 245, 246
Lion 194
Rabbit 196
Rodent 196
Toxodon 106
Incline 468
Incompetent bed rock 61
Incomplete mesentery 167
Incurrent pore 166
Incus 242
Indehiscent fruit 150
Index finger 230-231
India
Cretaceous period 72-73
Jurassic period 70
Himalaya formation 62-63
Late Carboniferous period 66
Middle Ordovician period 64
Mountain building 62-63
Quaternary period 76-77
Railroad track gauge 331
Tertiary period 74-75
Threophorans 92
Triassic period 68
Indian ocean 73, 75, 77, 265
Indian stick insect 192
Indicator
"Deltic" diesel-electric locomotive 327
Bus 333
Harley-Davidson FLHS Electra Glide 363
Honda CB750 363
MCW Metrobus 332
Volkswagen Beetle 340
Indicator assembly 352
Indicator board 542
Indicator lamp 353
Indicator lens 341
Indirect method mosaic creation 450-451
Indium 311
Indo-Australian plate 59
Inducer 418
Induction stroke 343
Indus 20
Indusium 121
Industrial Revolution 492
Inert gas 311, 584
Inferior articular process 225
Inferior concha 212, 241
Inferior extensor retinaculum 233
Inferior meatus 245
Inferior mesenteric vein 253
Inferior nasal concha 221, 241, 245
Inferior oblique muscle 241
Inferior orbital fissure 221
Inferior rectus muscle 241
Inferior vena cava 215, 252-253, 257
Infertile swamp 288
Infield 536-537
Infilled swamp 291
Inflated petiole 158
Inflation valve 405
Inflorescences 140
Aechmea miniata 162
Bromeliad 113
Catkin 144
Compound 142-143
Couch grass 113
Dodder 163
Stem arrangements 143
Inflorescence stalk 140-143
Aechmea miniata 162
Brassavola nodosa 162
Everlasting pea 129
Indehiscent fruit 150
Peach 131
Peruvian lily 129
Rowan 131
Russian vine 131
Succulent fruit 148
Vegetative reproduction 154-155
Wind-pollinated plant 144
Inflorescence types
Capitulum 129, 142
Compound umbel 143
Dichasial cyme 143
Raceme 129
Single flower 143
Spadix 143
Spherical umbel 143
Spike 143, 155, 162
Infraorbital foramen 221
Infraorbital margin 213, 221
Infrared radiation 318-319
Energy emission from Sun 22
Infrared map of our galaxy 15
Infrared board 579
Infrared camera 578
Infrared receiver 580
Infrared projector 578
Infrared sensor 609
Infraspinatus muscle 227
Infratemporal fenestra
Baryonyx 83
Camarasaurus 91
Diplodocus 90
Heterodontosaurus 83
Lambeosaurus 99
Panoplosaurus 94
Parasaurolophus 99
Plateosaurus 88
Protoceratops 102
Triceratops 103
Infratemporal foramen 106-107
Ingres paper 441
Initial cave 285
Ink 430, 444
Ink-cartridge replacement button 574
Ink cartridges 574
Ink dabber 446
Inkjet nozzle 575
Inkjet printer 574-575
Ink outlet hole 574
Ink pad 445
Ink reservoir 444, 575
Ink roller 448, 449
Ink sac 176
Ink stick 444
Ink stone 444
Inlay 488-489
Inlet 295
Inlet cone 418
Inlet manifold
Daimler engine 343
Jaguar V12 engine 345
Mid West single-rotor engine 411
Inlet manifold tract 345
Inlet-over-exhaust (IOE) engine 362
Inlet port 345, 367
Inlet rotor 347
Inlet tract 410
Inlet valve 345, 345, 362
Inner bin fin 592
Inner bud scales 134
Inner cage assembly 599
Inner clutch drum 366
Inner core 38-39, 41
Inner counter 445
Inner cyclone cone 592
Inner dome 484
Inner floret 129, 142
Inner jib downhaul 585
Inner jib halyard 385
Inner jib stay 382
Inner jib tack 382
Inner layer of cortex
Dicotyledon 127
Epiphytic orchid 162
Monocoyledon 127
Wetland plants 158-159
Inner mantle 44-47
Inner martingale stay 383
Inner membrane 139
Inner planetary orbits 31
Inner posts 528
Inner tepal 126, 140, 143
Inner tube 359, 424, 507
Inner vane 191
Innings 536, 538
Inorganic substances 280
Inscription 488
Insectivorous plants 113, 160-161
Insects 168-169, 279
Cretaceous 72-73
Plant food 160-161
Pollinators 144-145
Inselberg 283
Insoluble solids 312
Inspection cover
Avro biplane 403
Lockheed Electra airliner 407
Inspection door 407
Inspection panel 417
Inspiration 255
Instep 211
Instrument bay 613
Instructor's cockpit 403
Instrument console 420
Instrument deployment device 615
Instrument landing system aerial 420-421
Instrument module 613
Instrument panel
ARV light aircraft 425
Bell-47 helicopter 422
Renault Clio 353
Schweizer helicopter 426
Insulating column 316
Insulating hair 104, 107
Insulation 300
Insulator
Electric circuit 316
Generating magnetism 317
Hydroelectric power station 314
Intaglio printing 446-447, 448
Intake manifold 351, 354
Intake pipe 335
Intake port 346
Integral ink reservoir 444
Integrated transparency unit (TPU) 570, 571
Integrated transport system 332
Integument
Ovule 147
Scots pine 122
Intelligent electronic door-lock 602
Intentional foul 533
Interalveolar septum 254
Intercellular leaf space 139
Interception 526
Inter-City travel 332
Intercolumniation 461, 485
Intercompressor bleed valve 419
Intercompressor diffuser pipe 419
Intercostal muscle 91, 255
Interdental papilla 247
Interdental septum 247
Interglacial period 76
Integer house 602, 603
Interior light 353
Interlobular artery 256
Interlobular vein 256
Interlocking spur 289
Intermediate housing 346
Intermediate lamella 225
Intermediate ring 563
Internal capsule 237
Internal carotid artery 243, 252
Internal combustion engine
First cars 334
Motorcycle engine 366
Pioneers of flight 398
Internal crust 28
Internal elastic lamina 252
Internal fuse overload protection 585
Internal iliac artery 215, 253
Internal iliac vein 253
Internal jugular vein 253
Internal skeleton 174
Internal spermatic fascia 259
Internal urethral orifice 257
Internal urethral sphincter muscle 257
International referees signals 533
International rules 532
International squash 544-545
International track gauge 331
Internet 576-577
Internet service provider (ISP) 576
Internode
Canadian pond weed 158-159
Horsetail 120
Ice-plant 129
Live-forever 129
London plane 134
Rhizome 155
Rock stonecrop 128
Rose stem 130
Stem 134
Stolon 154
Interopercular bone 181
Interosseous ligament 232
Interphalangeal joint
Baryonyx 85
Human 231, 233
Interplane strut 599, 404-405
Interradicular septum 247
Interrupter gear 404
Interstellar cloud remains 613
Intertragic notch 242
Intertrochanteric line 225
Intertropical convergence zone 300
Interventricular septum 251
Intervertebral disc 212, 218, 223, 245, 261
Intestinal muscle 226
Intestine
Bony fish 181
Butterfly 169
Chimpanzee 202
Cow 198
Crayfish 173
Dogfish 179
Dolphin 205
Elephant 200
Frog 182
Gallimimus 86
Human 214
Large 195, 202
Lizard 185
Sea urchin 175
Small 182, 185, 187, 195, 198, 200, 202
Spider 170
Tortoise 187
Intrados 469, 484
Introitus 258
Intrusive rocks 26, 275
Invasion stripes 409
Invertebrates
Earth's evolution 56
Fossil record 279
Insects 168-169
Marine 65
Inverted ovolo 486
Inverter 355
Inverter board 570
Inverter cooling fan 355
Inverter cooling fan connector 355
Inverter housing 355
Inward dive 558, 559
Io 44
Iodine 311
Ion 308
Ionic bonding 308
Ionic capital 460
Baroque church 481
French temple 485
Renaissance building 476
Ionic column
Baroque church 481
French temple 485
Neoclassical building 483
Ionic half-column 464
Ionic order 460
Iota Centauri 21
Iota Pegasi 19
Iota Sagittarii 21
iPhone 4 588
Ipomeoa batatas 154
Iran 331
Ireland 331
Iridium 311
Iridocorneal angle 241
Iris
Human 213, 226, 241
Linear leaf 137
Octopus 177
Iris lazica 137
Iron 311
Earth's composition 39
Earth's crust 58
Golf club 547
Magnetic domains 317
Meteorite 52
Nineteenth-century buildings 492
Structure of Mercury 35
Structure of Venus 37
Iron armature support 455
Ironclad 392-393
Iron club 546-547
Iron filings 317
Iron hull 392-393
Iron oxide
Earth pigments 434
Flesh-colored pigments 433
Sanguine crayon 430
Sedimentary rocks 267, 277
Iron oxide dust 42
Iron paddlesteamer 392-393
Iron pyrite 79, 270
Iron railing 493
Iron roof 479
Iron ship 392-393
Iron, steam 594
Iron tracery 493
Iron tire 334
Ironwork 478, 482
Irregular galaxy 10-12, 15
Irreversible reactions 312
Ischial tuberosity 224
Ischium
Archaeopteryx 85
Bird 189
Crayfish 173
Diplodocus 90
Eryops 81
Euoplocephalus 94
Frog 185
Human 218, 224
Iguanodon 96
Ornithischian 82
Parasaurolophus 98
Plateosaurus 88
Saurischian 82
Stegoceras 100-101
Stegosaurus 93
Struthiomimus 87

Triceratops 102
Tyrannosaurus 84
Ishtar Terra 36-37
Islamic buildings 488-489,
Islamic mosaic 489
Islands 291, 294
Isocline 61
Isolated single boulders 286
Isolated steep-sided hill 283
Isolator valve 325, 327
Isosceles triangle 622
Isoseismal lines 63
Isotopes 310
ISP 576
Israel 293
Isthmus
Reproductive system 258-259
Water hyacinth 158
Italian State Railroads Class 402 328
Italic Roman lettering 445
Item link 577
Itonaco 434
Ivy 130-131, 137

J

Jack 514
Jacket-wall 466
Jack-rafter 473
Jack staff
Battleship 394
Frigate 397
Square-rigged ship 375
Wooden sailing ship 379
Jacob's ladder 378
Jagged fracture 270
Jaguar straight six engine 344
Jaguar V12 engine 345
Jali 488-489
Jamb
Ancient Roman temple 463
Baroque church 479
Medieval church 468
Neoclassical building 478, 482-483
Nineteenth-century building 492
Jami Masjid 488
Javelin 542-543
Jaw
Brace-and-bit 601
Hand drill 601
Human 212, 220-221
Power drill 601
Rope 389
Jawbone
Allosaurus 85
Australopithecus 107-108
Ceratopsian 100
Dolphin 204
Horse 105
Human 220, 247
Ornithopod 96
Shark 178
Snake 184
Theropods 84
Jawless fish 78, 178-179, 180
JBL Spyro speakers 586
Jeer 377
Jejunum 249
Jelly 192
Jellyfish 78, 166-167
Earth's evolution 56
Fossil record 279
Jet engine 412, 418-419
Jetliners 412-415
Jet pipe 418-419, 423
Jet pipe connection 419
Jetstream 300, 418
Jewel anemone 166
Jewel Box 11
Jewish calendar 618
Jib boom 379, 382
Jib fairhead 561
Jib halyard 380
Jibsail 378, 379, 385
Jib sheet 385
Jib stay 382
Jib tack 382, 383
Jockey 554-555
Jockey wheel 358
Jodhpurs 554
Joint
Cave 284-285
Coastline 295
Faults and folds 61
Jointed plug 19
Weathering and erosion 282
Jointed leg 79, 168
Jointed pincer 79
Jointed solidified lava 292
Jointed stem 131
Joints 224-225, 608
Joist 464, 486
Jones, H. 493
Jordan 293
Jordan River 293
Journal 347
Joystick 361, 520
Judo 556-557
Jugal bar 201
Jugal bone 96, 102-103
Jugal plate 94
Juglans nigra 137
Jugular vein 215
Juice sac 148
"Jumbo jet" 412
Jumps 552, 554
Jump seat 337
Jump shot 532, 535
Junction
Electrical circuit 316
Giornata 434-435
Photovoltaic cell 605
Junction board 355
Juncus sp. 135
Junior ratings' mess 397
Junk 376
Junk mail folder 576
Junk ring 343
Jupiter 30-31, 44-45, 614
Jupp-Reese winglet 572
Jurassic period 70-71
Fossil record 279
Geological time 57
Jury mast knot 389
Justicia aurea 144
Juvenile volcano 275
JVC Everio camcorder 582

K

Kabe 375
Kaibab limestone 276
Kaibab Plateau 277
Kaiparowits formation 276
Kaiparowits Plateau 277
Kalahari Desert 265
Kalanchoe daigremontiana 154
Kalasa finial 489
Kalos 372
Kame delta 286
Kame terrace 286
Kangaroo 206-207
Kappa Pegasi 19
Kara Kum 265
Karv 374
Kasugado Shrine of Enjoji 490
Kasuga-style roof 490
Katastroma 373
Kaus Australis 19, 20
Sagittarius 21
Kaus Borealis 21
Kaus Meridionalis 21
Kawana House 496
Kawasaki industrial robot 609
Kayak 560
Kayenta formation 276
Kazakstania 65
Kedrostis africana 113
Keel
Battleship 395
Bird 189
Frigate 397
Ironclad 393
Iron paddlesteamer 392
Longboat 380
Sailing warship 377
Viking ship 374-375
Wooden sailing ship 378
Keel boat 560
Keeled lesene 486
Keeler 41
Keelson (Kelson) 560
19th century paddle steamer 391
Ironclad 393
Keep 466
Keeper ring 562
Kelvin temperature scale 590
Kendo 556
Kentrosaurus 92-93
Kepler 40
Keraia 372
Keratin 234
Kestrel 189
Ketch 384, 385
Kettle 286
Kettle drum 519
Kettle lake 293
Post-glacial valley 286
Kevlar 384, 388
Key
Concert grand piano 515
Home keyboard 520
Motorcycle clutch 366
Musical notation 502
Steel lock 360
Synthesizer 520
Upright piano 514
Woodwind instruments 508-509
Keyboard 521, 566, 611
Keyboard instruments 514-515, 520
Key guard 509
Keypad 589
Key rod 509
Key signature 502
Keystone 484
Ancient Roman building 463, 465
Baroque church 479, 481
French temple 485
Medieval church 469
Neoclassical building 478, 482
Renaissance building 476-477
Keyway 390
Kick-stand 363
Kick-starter 363, 366
Kidney
Bird 189
Bony fish 181
Brachiosaurus 90
Dogfish 179
Dolphin 205
Domestic cat 195
Elephant 200
Frog 182
Gallimimus 86
Human 215, 256-257
Lizard 185
Octopus 176
Rabbit 196
Snail 177
Tortoise 187
Kidney ore hematite 268
Kidney-shaped palette 436
Killer whale 205
Killick 386
Kiln 452
Kimberlite 268, 275
Kinetic energy 314-315
Kinetic sculpture 452
King pin 358
King-post 473, 479
Early monoplane 400-401
Pegasus Quasar ultralight 427
Pegasus XL SE ultralight 426
King-post strut 401
King spoke handle 390
Ring strut 464
King vulture 190
Kirby BSA racing sidecar 369
Kittiwake 190
Kiwis 188
Knee
Anchisaurus 89
Corythosaurus 98
Faering 375
Gorilla 203
Horse 199
Human 211
Iguanodon 96
Kangaroo 207
Lion 195
Pachycephalosaurus 100 '
Psittacosaurus 103
Rabbit 197
Stegoceras 101
Stegosaurus 92
Tyrannosaurus 84
Wooden ships 381
Knee joint
Brachiosaurus 90
Diplodocus 90
Euoplocephalus 94
Human 219
Parasaurolophus 98
Plateosaurus 88
Stegoceras 101
Struthiomimus 87
Toxodon 107
Triceratops 102
Tyrannosaurus 84
Knee of the head 378
Knee pad 527, 534
Knee roll 539, 554
Knife
Palette 436
Relief printing 446, 449
Knighthead 380
Knots 388-389
Knuckle 210
Koala 207
Kochab 18
Kope 372-373
Korolev 41
Krypton 311
Kuan Han-ch'ing 35
Kubernetes 372
Kuiper belt 30, 50
Kunzite 271
Kuroshio current 297

L

Labellum 126, 145
Label mold 481
Labia 258
Labial palp 168
Labrum 168
Laburnum x watereri 137
Laccolith 273-275
Lacerta 19, 20
Lacertilia 184
Lacrimal apparatus 241
Lacrimal bone
Bony fish 181
Human 221
Protoceratops 102
Lacrimal canaliculus 241
Lacrimal gland 241
Lacrimal punctum 241
Lacrimal sac 241
Lacrosse 540-541
Lacuna
Bones and joints 225
Clubmoss 120
Mare's tail 135
Wetland plants 158-159
Lacustrine terrace 286
Lada Terra 36, 37
Ladder
74-gun ship 381
Battleship 394
Frigate 396
Iron paddlesteamer 392, 393
Roman corbita 372-373
Train equipment 330
Wooden sailing ship 378
Ladder way 395-396
Lady Chapel, Salisbury Cathedral 470
Lagomorpha 196
Lagoon
Atoll development 299
Coastline 294-295
River features 290-291
Lagoon Nebula 21
Lagopus lagopus 193
Lagostomus maximus 197
Lake Baikal 265
Lake Erie 264
Lake Huron 264
Lake Michigan 264
Lake Nyasa 265
Lake Ontario 264
Lakes 292-293
Glacier 286-287
Groundwater system 293
Igneous rock structures 275
River features 290
River's stages 289
Rock cycle 266-267
Weathering and erosion 283
Lake Superior 264
Lake Tanganyika 265
Lake Victoria 265
Lakshmi Planum 37
Lambda Andromedae 19
Lambda Pegasi 19
Lambdoid suture 220
Lambeosaurus 96, 98-99
Lamb, T. 494
Lamella 139
Lamina 136
Butterwort 161
Couch grass 113
Dicotyledon leaf 127
Human 222-223
Leaf 158
Monocotyledon leaf 127
Seaweed 116-117
Succulent 113
Vegetative reproduction 154
Water hyacinth leaf 158
Water lily leaf 159
Laminaria digitata 116-117
Laminates 548
Lamium sp. 135
Lamp 570, 571
Lamp bracket 336, 342
Lamp cluster 341
Lampland 43
Lamprey 178
Lampropeltis ruthveni 184
Lampropeltis triangulum annulata 184
Lamp shield 350
Lanceolate leaf 120, 131, 136
Lancet 471
Lancet arch 473, 484
Lancet window 470-472
Land 39
Amphibians 80
Animals 64
Atmosphere 301
Plants 56, 64
Rivers 288
Vertebrates 82
Landau body 334
Landau iron 334
Landing 477
Landing and taxiing light 414
Landing gear 406-407, 424-425, 573
Landing-gear muffler 423
Landing gear door
BAe-146 components 414
Concorde 416
Hawker Tempest components 409
Lockheed Electra airliner 406-407
Landing gear drag strut 401
Landing gear fork 407
Landing gear front strut 400, 404
Landing gear hydraulics 417
Landing gear leg 424
Landing gear rear cross-member 400
Landing gear rear strut 400-401
Landing gear strut 405
Landing light
BAe-146 jetliner components 414-415
Bell-47 helicopter 422
Lockheed Electra airliner 407
Schweizer helicopter 423
Landing skid
Avro triplane 403
Blackburn monoplane 400-401
Helicopter 422-423
Wright Flyer 399
Land movement 59
Land plants 56, 78
Landscape features 290-291, 294
Land surface removal 282
Land turtle 186
Lane
Athletic track 542
Swimming pool 558
Lane time-keeper 558
Langrenus 40
Language 108
Langur 202
Lantern 486
Baroque church 480-481
French temple 485
Neoclassical building 478-479
Twentieth-century building 494
Wooden sailing ship 379
Lanthanides 310
Lanthanum 310
Lanyard
Lifejacket 561
Oar 373
Rigging 382-383
Roman corbita 373
Lap 542
Lapilli 272
Lap strap
ARV light aircraft 425
Curtiss biplane 398
Lockheed Electra passenger seat 407

Pegasus Quasar ultralight 427
Laptop computer 566, 567
Laptops 567
Large intestine
Brachiosaurus 90
Chimpanzee 202
Domestic cat 195
Euoplocephalus 94
Human 214
Large Magellanic Cloud
Hydrus and Mensa 20
Our galaxy and nearby galaxies 15
Stars of southern skies 20-21
Large mammals 57
Larkspur 141, 151
Larus marinus 193
Larus ridibundus 193
Larva 168
Laryngeal prominence 212, 244-245
Larynx
Amphibian 182
Human 214-215, 244
Laser ranger 420
Lateen sail 375, 376, 384
Lateral angle 213
Lateral bracing strut 402-403, 416
Lateral branch
Adventitious roots 158-159
Horsetail 120
Vegetative reproduction 154
Lateral bud 134
Begonia 129
Dicotyledon 127
Horse chestnut 130
Leaf scars 154
London plane tree 134
Rhizome 155
Rowan twig 131
Stem bulbil 155
Stolon 154
Lateral canal
Human 247
Starfish 174
Lateral caudal musculature 87
Lateral column 223
Lateral control wheel 401
Lateral control wire 404
Lateral dorsal aorta 179
Lateral epicondyle 225
Lateral fault 61
Lateral fault lake 293
Lateral lacuna 257
Lateral line 181
Lateral malleolus 233
Lateral mass 222
Lateral moraine 286-287
Lateral plantar artery 253
Lateral plate 78
Lateral rectus muscle 240-241
Lateral root 133
Broomrape host 163
Carrot 128
Dicotyledon 127
Germination 152-153
Horse chestnut 130
Seedling 152-153
Strawberry 128
Sweet pea 128
Lateral root scar 128
Lateral sepal 141
Lateral shield 187
Lateral shoot 156
Lateral strike-slip fault 61
Lateral sulcus 237
Lateral tepal 126
Lateral vein 136, 159
Lateral ventricle 237
Lath 464
Lathyrus latifolius 129
Lathyrus odoratus 128
Latissimus dorsi muscle 227
Latrodectus mactans 171
Lattice-beam 496-497
Latticed screen 488-489
Latticed shade 495
Lattice-truss 499
Lattice window 492
Lattice-work 493
Laurasia
Cretaceous period 62
Jurassic period 70-71
Late Carboniferous period 66-67
Laurentia 65
Laurentian Library 474-475
Lava 62
Igneous and metamorphic rocks 274-275
Mountain building 62
Rock cycle 266
Volcano 272-273
Lava eruptions 272
Lava flow 273
Contact metamorphism 274-275
Mars 42
Rock cycle 266
Lava fragments 272
Lavatera arborea 131
Lava types 273
Lavinia Planitia 36-37
Lawrencium 311
Layering
Fresco 434-435
Pastel colors 440
Lay-up shot 532
LCD see Liquid crystal display (LCD)
LCD monitor 583
Leach 374, 384
Lead
Mineralization zones 281
Minerals 268
Periodic table 311
Lead covering 487
Leading block 394
Leading edge
Avro biplane 403
Avro triplane 403
BAe-146 components 413, 414-415
BE 2B tail 405
BE 2B wings 404
Blackburn monoplane 401
Concorde, the 416-417
Hawker Tempest components 409
Lockheed Electra airliner 406
Northrop B-2 bomber 421
Pegasus Quasar ultralight 427
Wright Flyer 399
Leading-edge aerial 421
Leading-edge fairing 425
Lead-in wire 319
Lead iodide 313
Lead nitrate 313
Lead shot 517
Lead wire 600
Leaf axis 137
Leaf bases 128, 136-137
Aechmea miniata 162
Couch grass 113
Dicotyledon 127
Florists' chrysanthemum 129
Guzmania lingulata 162-163
Hogweed 129
Monocotyledon 126-127
Sago palm 123
Seedling leaf 152
Water hyacinth 158
Leaf blade
Butterwort 161
Dicotyledon 127
Leaf surface 136, 138
Monocotyledon 127
Vegetative reproduction 154
Venus fly trap 160
Wetland plants 158-159
Leaf insect 192
Leafless branch 120
Leaflets 136-137
Everlasting pea 129
Fern 120-121
Horse chestnut leaf 130
Mahonia 130-131
Monocotyledon 126
Pinna 121, 136-137
Rose 131
Rowan 130
Sago palm 123
Tree fern 112-113
Leaflet stalk 137
Leaf-like structures 141-143
Dehiscent fruit 151
Dicotyledon flower 127
Guzmania lingulata 163
Ice-plant 129
Live-forever 129
Peruvian lily 129
Slender thistle 129
Wind pollination 144
Leaf margin 129
Aechmea miniata 162
Slender thistle 129
Vegetative reproduction 154
Leaf notch 154
Leaf primordium 134
Leaf scar
Begonia 129
Elder 130
Horse chestnut 130
Ice-plant 128-129
London plane 134
Rock stonecrop 128
Leaf shape 136-137
Leaf sheath 129
Leaf spring 338
Leaf spring suspension 327
Leaf stalk 128, 136-137
Chusan palm 130
Clematis 131
Cobra lily 160
Common horse chestnut 130
Dicotyledon 127
Everlasting pea 129
Florists' chrysanthemum 129
Kedrostis africana 113
Maidenhair tree 123
Monocotyledon 126-127
Mulberry 130
Oxalis sp. 157
Passion flower 130
Peach 131
Seedling 153
Strawberry 128
String of hearts 157
Tree fern 112
Tree mallow 131
Vegetative reproduction 154-155
Venus fly trap 160
Water lily 159
Wind pollination 144
Leaf succulents
Haworthia truncata 157
Lithops bromfieldii 157
Lithops sp. 156
Leaf trace 127
Leaf venation 129
Leafy liverwort 118
Leafy thallus 114
Lean-to roof 468-470, 472
Leather ball making 525
Leather grommet 373
Leather hood 334
Leather ink dabber 446
Leather pad 557
Leather upholstery 337
Leather valance 337
Leathery exocarps 148
Leaves 136-137
Abaxial surface 123, 130
Adaxial surface 123, 130
Aechmea miniata 162
Apex 136-137
Apical meristem 134
Barberry 130-131
Bishop pine I24
Brassavola nodosa 162
Bromeliad 112-113
Broomrape 163
Butterwort 161
Canadian pond weed 158-159
Carnivorous plants 160-161
Cheekerbloom 136
Chusan palm 130
Classification 136-137
Clematis 130-131
Clubmoss 120
Cobra lily 160
Couch grass 113
Dicotyledon 126-127
Dryland plants 156-157
Durmast oak 131
Epiphyte 162-163
Fern 120-121
Florists' chrysanthemum 129
Germination 152-153
Guzmania lingulata 162-163
Haworthia truncata 157
Hinge cell 113
Hogweed 129
Horsetail 120
Intercellular space 139
Ivy 131
Kedrostis africana 113
Lamina 136
Lithops bromfieldii 157
Liverwort 118
London plane tree 134
Maidenhair tree 123
Margin 136
Marram grass 113
Midrib 136
Monkey cup 161
Monocotyledon 126-127
Moss 112, 119
Mulberry 130
Orange lily 154
Oxalis sp. 157
Parasite host 163
Passion flower 130
Peach 131
Photosynthesis 134, 138-139
Pine 122, 124-125
Pitcher development 161
Pitcher plant 113, 160-161
Primordia 134
Rock stonecrop 128
Rose 130-131
Rosettes 162-163
Rowan 130
Sago palm 123
Scots pine 122
Seedling 152-153
Slender thistle 129
Smooth cypress 123
Stomata 139
Strawberry 128
Tendrils 161
Toadflax 129
Tree fern 112-113
Tree mallow 131
Vegetative reproduction 154-155
Veins 136, 138-139
Venus fly trap 160
Water fern 158
Water hyacinth 158
Water lily 159
Welwitschia 122-123
Xerophyte 156-157
Yew 123
Le Corbusier 494
LEDs 608
Leda Planitia 36, 37
Ledge 381
Leech 374, 384
Leechline 375
Left edge guide 575
Leg
Amphibian 182
Caiman 186-187
Crab 172
Crayfish 172-173
Crocodilian 186
Elephant 200
Frog 182
Gorilla 203
Human 210
Kangaroo 207
Lizard 184-185
Relief-printing press 449
Salamander 182
Scorpion 170
Shrimp 172
Spider 170-171
Tadpole 183
Terrapin 187
Tripod congas stand 519
"Leg before wicket" 538
Leg bud 260
Leg pad 539, 551
Leg protector 551
Leg slip 538
Legumes 150
Leibnitz 41
Lemercier, J. 486
Lemming 196
Lemon 148
Lemur 202-203
Lemur catta 203
Lena River 265
Lenoir, Etienne
Early engines 342
First cars 334
Lens
Flatbed scanner 570
Human body 241
Microscope 610, 611
Lens cover 581
Lens cover assembly 582
Lenticels 130-131, 134
Lentiform nucleus 237
Leo 18, 21
Leo Minor 18, 21
Leonaspsis 279
Leonid meteor shower 52
Leontopithecus rosalia 203
Lepidodendron 66-67
Lepidoptera 168
Lepidotes maximus 73
Leptoceratops 103
Lepus 21
Lesbian leaf pattern 460
Lesene
Ancient Roman building 462, 465
Baroque church 480-481
Dome 486
French temple 485
Gothic church 473
Renaissance building 476-477
Lesser trochanter of femur 225
Lesser wing covert 188
Lesser wing of sphenoid bone 221
Letronne 40
Lettering 444-445
Levator anguli oris muscle 229
Levator labii superioris muscle 229
Levator palpebrae superioris muscle 241
Levee 289-291
Level-wind system 562
Lever 320-321
Le Verrier ring 50-51
LG Optimus 2X 588
Liang K'ai 35
Libellulium longialatum 73
Liberty ship 392
Libra 18, 21
Library 483, 496
Licence holder 332
Lichens 114-115
Lid
Moss 119
Pitchers 161
Ships for war and trade 377
Lid assembly 571
Lierne 469
Life 56, 78-79, 300
Lifeboat 394
Lifeboat davit 395
Life buoy 395
Life-cycle
Brown seaweed 117
Fern 121
Insect 168
Moss 119
Mushroom 115
Plants 112
Scots pine 122
Lifeguard 332
Lifejacket 561
Life of massive star 26-27
Life of small star 24-25
Life-raft 416
Liferaft cylinder 397
Lift
Athletics 543
Center Georges Pompidou 497
Double topsail schooner 385
Roman corbita 372
Sailing warship 376-377
Wooden sailing ship 378
Lift bracing wire
Biplanes and triplanes 403
Early monoplane 400-401
Pegasus Quasar ultralight 427
World War I aircraft 404-405
Lifting handle 336
Lifting lug 330
Lift spoiler 413, 414
Lift wire 399
Ligament
Bifurcate 232
Cricothyroid 244
Deltoid 252
Falciform 248
Foot 232
Hip joint 224
Iliofemoral 224
Interosseus 232
Ovarian 258
Periodontal 247
Plantar calcaneonavicular 232
Posterior cuneonavicular 232
Posterior tarsometatarsal 232
Pubofemoral 224
Talonavicular 232

Zonular 241
Ligature 508, 509
Light 314-315, 318-319
Chemical reactions 312
Renaissance building 474
Seed germination 152
Translucent "window" 157
Twentieth-century building 495
Ultraviolet 145
Light aircraft 410, 424-425
Light Emitting Diode 583
Lighterman's hitch 389
Light hour 14
Lighting hole 393
Light level sensor 581
Lightning 45, 316
Lights
Bicycle 360
MCW Metrobus 332
Light screen 394
Light shield 612, 613
Light switch 339
Lightweight plastic intake manifold 354
Light-well 487
Light year 14
Lignite 280
Lignum vitae bearing 387
Ligulate ray floret 129
Lilienthal, Otto 398
Lilium bulbiferum 154
Lilium sp. 133, 138, 140-141, 155
Lily
Bulbil 154-155
Flower 140-141
Leaf surface 138
Limb
Mammal 104
Paddlesteamer 390
Reptile 80
Structure of a fold 60
Limber hole 393
Lime 143
Lime-resistant pigment 434
Limestone
Cave 284
Contact metamorphism 274
Faults and folds 60
Fossilized blue-green alga 78
Lower Carboniferous 60
Limestone block 470
Limestone cladding 494
Limestone false door 459
Limestone spring 292
Limestone strata 284
Lime water 313
Limonite groundmass 268-269
Limpet 176
Linaria sp. 129
Line 562
Linea alba 226
Linear dune 283
Linear leaf 129, 137
Linebacker 526
Line guide 563
Line judge 526
Line of sight 41
Linesman
Badminton 545
Gaelic football 529
Ice hockey 550
Soccer 524
Tennis 544
Volleyball 534
Lingual nerve 244
Lingual tonsil 245
Link 386
Linocut 446
Linoleum block 446, 449
Linseed oil 436
Lintel
Building 459, 494
Coastline 295
Lintel course 483
Lion 194-195
Lion crest 395
Lionfish 180
Lip
Flower 126, 145
Human 212-213
Lamprey 178
Pollination 145
Lip of trunk 200-201
Lip plate 508, 508
Lip tension 506
Liquidambar styraciflua 76
Liquid capacity measurements 590
Liquid crystal display (LCD)
Apple iPad 568
Garmin Etrex handheld GPS 591
HP Pavilion DV4 laptop 567
JVC Everio camcorder 582-583
Nikon Coolpix S1000PJ 580
Liquid helium 45
Liquid hydrogen 44-47
Liquid ink 444
Liquids 306-307
Litchi chinensis 148
Lithification 266
Lithium 308, 310
Lithium fluoride molecule 308
Lithium-ion battery 589
Lithium-ion rechargeable battery 579
Lithium-polymer battery 569
Lithographic printing 446
Lithographic printing equipment 448
Lithops bromfieldii 157
Lithops sp. 156
Lithosphere 58-59
Little finger 230-231
Little grebe 190
Little toe 232-233
Live-forever 128-129
Liver
Bird 189
Bony fish 181
Chimpanzee 202
Dogfish 179
Dolphin 205
Domestic cat 195
Euoplocephalus 94
Frog 182
Gallimimus 86
Human 214, 248, 252
Lizard 185
Rabbit 196
Tortoise 187
Liverworts 112, 118-119
Livestock freight car 327
Living organisms 306
Lizard 184-185, 382
"Lizard-feet forms" 88
Lizard-hipped dinosaurs 82, 88-89
Llama 198
Load 320-321
Loading arm 396
Loading gauge 330-331
Load space 334
Lobby 498
Lobe
Liverwort 118
Venus fly trap 160
Lobed leaf 129, 131
Lobsters 172
Lobule 242
Local Arm 14
Local control cabinet 396
Lock button 600
Lock forward 530
Lockheed Electra airliner 406-407
Locking lever 590
Lock nut 351, 359
Locks 360
Lock washer 358-359
Locomotion 104
Locomotives 324-329
Lodging knee 381
Loft 477
Log basket 334
Logic board 581
Loin
Horse 198
Human 210
London Bridge 466-467
London plane tree 134
Longboat 380
Long bridge 515
Long-distance cycling 360
Long-distance running 542
Longeron 403, 424
Longitudinal channels 120
Longitudinal fissure 236-237
Long jump 542-543
Long leading-link fork 362
Long leg 538
Long off 538
Long on 538
Long pass 532
Long radius turns 552
Longrod stabilizer 549
Longship 374-375
Longshore drift 294-295
Long-travel suspension 368
Long-wave radio 318
Look out periscope 396
Loom 560
Loop 388-389
Looped prominence 32-33
Loophole
Medieval building 466-469
Renaissance building 477
Loop of Henlé 256
Loose forward 530
Loose-head prop 530
Lopolith 274
Lora 127, 130
Lorises 202
Lost-wax casting method 454
Lotus flower 488
Lotus petal 489
Loudspeaker 520
Lounge 392
Louvre 493, 498
Love-in-a-mist 150-151
Lowell 43
Lower Carboniferous Limestone 60
Lower crankcase 410
Lower crux of antihelix 242
Lower deadeye 382-383
Lower deck 395
Lower-energy radiation 22
Lower epidermis 139, 159
Lower equipment module 614
Lower eyelid 213
Lower fin 423
Lower haze 37
Lower LCD assembly 579
Lower lobe of lung 215, 254-255
Lower seed axis 152-153
Lower topsail 385
Lower-wing attachment 404
Lower yard 395
Low gain antenna 615
Lowland coastline 295
Low Neap tide 297
Low pressure areas 300, 302-303
Low pressure gases 306
Low tides 296-297
Low-voltage supply 596
Loxodonta africana 200
Lozenge 471, 485
Lubricant 366
Lucarne window 480-481, 486
Lufengosaurus 89
Luff 384-385
Lug 382, 386
Lugger 384
Lug sail
Junk 376
Sail types 384
Lumbar nerves 238
Lumbar vertebrae
Crocodile 186
Domestic cat 195
Hare 197
Horse 199
Human 222-223
Kangaroo 206
Platypus 206
Rhesus monkey 202
Seal 204
Lumbrical muscle 231
Lump hammer 452-453
Lunae Planum 43
Lunaria annua 151
Lunate bone 230
Lunette 480
Lung
Amphibian 182
Bird 189
Brachiosaurus 91
Chimpanzee 202
Dolphin 205
Domestic cat 195
Elephant 200
Euoplocephalus 94
Frog 182
Gallimimus 86
Human 214-215, 252, 254-255
Lizard 184-185
Rabbit 196
Snail 177
Snake 184
Spider 170
Tortoise 187
Lungfish 80, 81
Lunule 231
Lures 562-563
Lutetium 311
LVG CVI fighter 405
Lychee 148
Lycoming four-cylinder engine 423
Lycoming six-cylinder engine 422
Lycopodophyta 64, 120
Lymphocytes 253
Lynx 18, 21
Lynx helicopter 396
Lyra 19, 20
Lysosome 217

M

M22 (globular cluster) 21
Macaques 202
Macaws 190
Mach 41
Machine-gun 404-405
Machine heads 512-513
Mackenzie-Peace River 264
Mackerel angling 562
Maquette 455
Macrobius 40
Macrofibril 234
Macrospicule 33
Macs 566
Macula 240-241
Madagascar 265
Madreporite 174, 175
Madrillus sphinx 203
Maenianum summum 465
Magazine 548-549
Magellanic Cloud 15, 20
Maginus 40
Maglev train 328-329
Magma
Igneous and metamorphic rocks 26
Mountain building 63
Ocean floor 298-299
Rock cycle 266
Volcanoes 272
Magma reservoir
Igneous rock structures 275
Volcanic structure 273
Magnesium 310
Earth's composition 39
Earth's crust 58
Seawater salt content 296
Magnesium alloy oil sump pan 354
Magnesium housing for air intake 355
Magnesium riser 548
Magnet 598, 605
Magnet array 615
Magnetic axis 28
Magnetic compass 423
Magnetic field 38
Magnetism 316-317
Magneto
Avro triplane 402
Hawker Tempest components 408
Wright Flyer 399
Magneto drive 367
Magnetometer 614
Magnetosphere 38
Magnetron assembly 596, 597
Magnetron cooling fan 596, 597
Magnetron cooling fan mounting 597
Magnetron perforated heat sink 597
Magnitude 22
Magnolia 57, 72
Mahonia 130-131
Maidenhair tree 122-123
Maillot 386
Main deck passenger door 573
Main deck windows 573
Main engines 614
Main fan 596, 597
Main fan electrical supply 597
Main-line signaling system 330-331
Main motor casing 593
Main printed circuit board (PCB) 591
Mainrail head 379
Main sail
Dhow 376
Roman corbita 373
Sailing rigs 385
Square-rigged ship 375
Main screen 584
Mains earthing wire 596
Mains electricity supply lead 585
Main sequence star
Massive stars 26
Objects in universe 11
Small stars 24
Stars 22-23
Mains flex 594
Mains flex clamp 594
Main sheer strake 393
Main sheet
Longboat 380
Roman corbita 373
Sailing dinghy 561
Viking karv 375
Main shroud 378
Mains lead 597-598
Main spar bridge 413
Mains power on/off switch 585
Mains spade contacts 594
Main stay 377, 379
Mains supply lead 594
Maintenance button 574
Main topcastle 377
Main topgallant mast 377, 378
Main topgallant sail 379
Main topgallant stay 379
Main topmast 377, 379
Main topmast topcastle 377
Main topsail 379
Main topsail halyard 385
Main topsail yard 379
Main top yard 377
Main turbine 397
Main wale 381
Main wheel 426, 593
Main wing bracing-strut 401
Main wing-strut 427
Main yard
Dhow 376
Sailing warship 377
Wooden sailing ship 379
Maize 127
Major calyx 256
Major coverts 188, 191
Malachite 433
Malacostraca 172
Malaysia 331
Male
Bladder 257
Body 210, 211
Pelvis 259
Reproductive organs 259
Urinary tract 257
Male apex 119
Male catkin 144
Male cone 122-123, 24
Male fern 120-121
Male flower organs 140-143
Male flowers
Fertilization 146-147
Gymnosperms 122
Painter's palette 143
Seaweed 116-117
Succulent fruit 148
Wind-pollinated plant 144
"Mallard" express steam locomotive 324-325
Mallet
Marble carving 452
Ships and sailing 383, 384, 388
Tubular bells 516
Malleus 242
Malpighian tubule
Butterfly 169
Spider 170
Malus 373
Malus sp. 126
Malus sylvestris 149
Mammals 104-107
Carnivora 194
Cetacea 204
Cretaceous period 72
Earth's evolution 56-57
Fossil record 279
Jurassic period 70
Lagomorpha 196
Large 57
Marsupalia 206

Monotremata 206
Pinnipedia 204
Primates 202
Proboscidea 200
Rodentia 196
Shrewlike 70
Small 56
Tertiary period 74-75
Ungulates 198
Mammoth 107
Mammut 75
Mammuthus 76, 77, 104
Mandapa 491
Mandarinfish 180
Mandible
Acanthostega 80
Ankylosaurus 94
Arsinoitherium 104
Baryonyx 83
Bat 105
Bear 194
Beetle 168
Bird 188-189
Bony fish 181
Camarasaurus 91
Chimpanzee 202
Crayfish 173
Crocodile 186
Diplodocus 90
Elephant 201
Eryops 80
Euoplocephalus 94
Hare 197
Heterodontosaurus 83
Horse 199
Human 220-221, 244-245
Hyaenodon 107
Iguanodon 96
Kangaroo 206
Lambeosaurus 99
Lion 194
Moeritherium 105
Panoplosaurus 94
Parasaurolophus 99
Phiomia 105
Plateosaurus 88
Protoceratops 102
Rattlesnake 185
Rhesus monkey 202
Seal 204
Stegoceras 100-101
Styracosaurus 102
Toxodon 106
Triceratops 103
Turtle 187
Tyrannosaurus 84
Mandrills 202-203
Mane 194, 199
Manganese 281, 310
Manharness knot 389
Manifold connector 355
Manilla rope 389
Manipulator 610
Man-of-war 378
Mansard roof 490
Mantellisaurus 96-97
Mantle
Earth 38-39, 58-59, 63
Mars 43
Mercury 35
Moon 41
Mollusks 176-177
Neptune 51
Pluto 51
Regional metamorphism 274
Uranus 49
Venus 37
Maple 127
Map projections 264-265
Maracas 504, 516-517
Marble 274
Marble block 453
Marble breaking equipment 450
Marble mosaic 489
Marble sculpture 452
Marble tessera 450
Marble veneer 462
Marchantia polymorpha 118
Mare Crisium 40
Mare Fecunditatis 40
Mare Frigoris 40
Mare Humorum 40
Mare Imbrium 40
Mare Ingenii 41
Mare Moscoviense 41
Mare Nectaris 40
Mare Nubium 40
Mare Orientale 41
Mareotis Fossae 43
Mare Serenitatis 40
Mare Smithii 41
Mare's tail 135
Mare Tranquillitatis 40
Mare Vaporum 40
Margaritifer Sinus 43
Margin
Lamina 116-117, 161
Leaf 129, 136-137
Needle 124
Water lily leaf 159
Marginal shield 187
"Margined heads" 100
Marginocephalians 83, 100-103
Maria 40
Marine invertebrates 65
Marine plants 56
Marine reptiles 57, 70
Marine sediments 280
Marine turtles 186
Mariopteris 66
Markab 19, 20
Markeb 21
Marlin 388
Marlinspike 383, 389
Marmosets 202
Marram grass 113
Mars 30, 42-43, 615
Mars Exploration Rover (MER) 615
Mars Exploration Rover spacecraft 615
Marsh 293
Marsupials 104, 206-207
Martellange, E. 479
Martingale 382, 557
Martingale stay 383
Mary Rose 376
Mascaron 487
Mask 460, 487, 536
Ancient Roman building 465
Cathedral dome 484
Neoclassical building 482
Masonry apron 487
Mason's mark 470
Mason's tools 485
Mass
Atoms and molecules 309, 320
Earth 30
Jupiter 26, 44
Mars 30
Mercury 30
Neptune 31
Planets 30-31
Pluto 31
Saturn 31
Stars 22
Uranus 31
Venus 30
Massive habit 270-271
Massive stars 26-27
Mass measurements 590
Massospondylidae 89
Mass-production 338-339, 492
Mass transportation 332
Mast
Battleship 394
Frigate 397
Greek galley 372
Iron paddlesteamer 392
Junk 376
Longboat 380
Roman corbita 373
Sailing 561
Sailing warship 376-377
Submarine 397
Tea clipper 392
Three-masted square-rigged ship 375
Viking karv 375
Wooden sailing ship 378-379
Mast band 382
Master cylinder
Disc brake 365
Harley-Davidson FLHS
Electra Glide 363
Honda VF750 364
Master shipwright 374
Master's sea cabin 381
Masthead
Roman corbita 373
Viking karv 375
Wooden sailing ship 378
Mast head bend 389
Masthead pulley for tye halyard 375
Mast hoop 585
Mastoid fontanelle 220
Mastoid process 220, 242
Mast partner 381
Mast step 392
Mast truck 372
Matar 19
Match play 546
Maternal blood pool 260
Maternal blood vessel 260
Mathematical symbols 621
Mato Grosso 264
Matter 306-307
Electrical charge 316
Identification 312
Mature ruptured follicle 258
Mawsonites spriggi 65
Maxilla
Ankylosaurus 94
Baryonyx 83
Bear 194
Bony fish 181
Camarasaurus 91
Chimpanzee 202
Diplodocus 90
Elephant 201
Eryops 80
Euoplocephalus 94
Frog 183
Horse 105
Human 212, 220-221, 244-245, 246, 248
Iguanodon 96
Lion 194
Pachycephalosaurus 100
Prenocephale 100
Stegoceras 100
Toxodon 106
Maxillary fenestra 90
Maxilliped 173
Maxwellian diagram 318
Maxwell Montes 36, 37
Mazda RX-7 346
McLaren Mercedes MP4-13 356-357
MCW Metrobus 332-333
ME 262 fighter 408
Meadow cranesbill 144
Meadow rue 137
Meadow sage 145
Meander 461
Meanders 288-289, 290
Measurement units 620
Meatus 242-243
Mechanical semaphore signal 330
Mechanical weathering 282
Mechanics 350-351
Mechanism of respiration 255
Medallion 476
Media guide button 577
Medial epicondyle 225
Medial malleolus 233
Medial moraine
Glaciers 286-287
River's stages 289
Medial rectus muscle 240-241
Median canal 243
Median cubital vein 253
Median eye 170
Median glossoepiglottic fold 244
Median nerve 238
Median sulcus 244
Median wing coverts 188
Medieval castles 466-467
Medieval churches 468-469
Medieval houses 466-467
Medinet Habu, Egypt 459
Mediterranean Sea 74, 265
Mediterranean sea anemone 166
Medium-wave radio 318
Medulla 114, 234, 256
Medulla oblongata 212, 236-237
Medullary cavity 224
Medullary pyramid 256
Medullary ray 125
Medullosa 66
Megaspores 122
Megazostrodon 104
Megrez 19
Meiolania 77
Meissner's corpuscle 234-235, 239
Mekong River 265
Melanin 234
Melanosaurus 68, 88-89
Melon 149, 205
Melting glacier 286, 289
Meltwater 287, 289
Meltwater pool 286
Membrane
Chloroplasts 139
Chorioallantoic 192
Egg 193
Shell 192
Thylakoid 139
Memory stick 581
Mendel 41
Mendeleev 41
Mendelevium 311
Meninges 237
Menkalinan 21
Menkar 19, 20
Menkent 21
Mensa 20, 21
Mental foramen 213, 220-221
Mentalis muscle 229
Mental protuberance 221
Mental symphysis 220
Mentolabial sulcus 213
Menu key 590
Merak 19
Merchants' Exchange 493
Mercury 30, 34-35
Mercury (metal) 281, 311, 319
Mericarp 151
Meristematic cells 154
Merlon 466
Mermaid's purses 192
Mersenius 40
Merus 172, 173
Merycoidodon 75
Mesa 275, 277, 282
Mesentery 167, 182
Mesocarp 146-147, 148, 148-149
Mesoglea 167
Mesohyal 166
Mesophyll 135
Bishop pine needle 124
Dicotyledon leaf 126
Marram grass 113
Monocotyledon leaf 126
Palisade layer 139
Spongy layer 139
Mesosphere 300
Mesothorax 168
Mesozoic era
Cretaceous period 72
Dinosaurs 82
Fossil record 279
Geological timescale 57
Jurassic period 70
Reptiles 80
Triassic period 68
Mess 597
Message area 576
Message display area 576
Metacarpals
Archaeopteryx 85
Arsinoitherium 104
Baryonyx 85
Bird 189, 91
Brachiosaurus 91
Cow 198
Diplodocus 90
Domestic cat 195
Elephant 90, 201
Eryops 80
Euoplocephalus 94
Frog 183
Gallimimus 86
Hare 197
Horse 198-199
Human 218-219, 230
Kangaroo 206
Lizard 184
Parasaurolophus 99
Plateosaurus 88
Platypus 206
Rhesus monkey 202
Seal 204
Stegoceras 100
Toxodon 106
Triceratops 103
Tyrannosaurus 84
Metacarpophalangeal joint 85
Metal cook/grill tray 596
Metal grill/griddle 596
Metalliferous muds 299
Metalling 486
Metal modeling implements 452
Metal needle pad 384
Metal nib 444
Metal riser 455
Metal runner 455
Metals 310
Metal tire 324
Metal wire conductor 316-317
Metamorphic aureole 26
Metamorphic rocks 26, 274-275, 266-267
Metamorphosis
Amphibian 182
Frog 183
Insect 168
Metasoma 170
Metatarsals
Albertosaurus 84
Archaeopteryx 85
Brachiosaurus 90
Crocodile 186
Domestic cat 195
Elephant 201
Eiyops 81
Euoplocephalus 94
Frog 183
Hare 197
Horse 199
Human 218-219, 232
Iguanodon 96-97
Kangaroo 206
Lizard 184
Parasaurolophus 98
Plateosaurus 88
Platypus 206
Rhesus monkey 202
Scorpion 170
Seal 204
Spider 171
Stegoceras 100-101
Struthiomimus 87
Toxodon 107
Triceratops 102
Metathorax 168
Metaxylem 127, 132-133
Meteor 52, 301
Meteorite
Asteroids, comets, and meteoroids 52
Earth's atmosphere 38
Moon 41
Ray crater 34
Meteorite impact 34, 40
Meteoroids 52-53
Solar system 30
Methane
Jupiter 45
Neptune and Pluto 50-51
Saturn 47
Uranus 48-49
Methane cirrus clouds 50-51
Metis Regio 36
Metope 460
Metric-Imperial conversions 620
Metric unit measurements 590
Metridium senile 166
Metrobus 332-333
Metrolink tram 332
Mexican hat plant 154
Mexican mountain king snake 184
Mexican true red-legged tarantula 170
Mexico 331
Mezzanine 467, 496
Miaplacidus 21
Mica 26, 270
Mice 104, 196
Michelangelo 35
Micrasterias sp. 112
Microfilament 217
Microneedle 606
Microorganisms 38, 78
Microphone 581
Micropipette 606
Microporous filter 592
Microprocessor
Personal computer 567
Digital camera 580
Microscopes 610-611
Microsoft Kinect 578
Microsoft Zune HD 587
Microsporangium 122
Microspores 122
Microsporophyll 122
Microtubule 217, 239
Micro-USB (Universal Serial Bus) socket 589
Microwave oven 315
Microwave radiation 10
Microwave combination oven 596-597
Microwaves 318, 596
Midbrain 236
Middle ear ossicles 242
Middle finger 230-231
Middle leg
Beetle 168
Bumblebee 168
Butterfly 169
Middle lobe of lung 215, 254-255
Middle meatus 241, 245
Middle nasal concha 212, 221, 241, 245

Middle phalanx 219, 230, 232
Middle rail 381
Midfielders
  Gaelic football 529
  Lacrosse 541
  Soccer 524
Midgut 173
Mid-latitude band 36
Mid-latitude cyclones 302
Mid-ocean ridge 281, 298-299
Mid-off 538
Mid-on 538
Midrib
  Dicotyledon leaf 126-127
  Durmast oak leaf 131
  Fern fronds 121
  Hogweed leaf 129
  Ice-plant leaf 129
  Live-forever leaf 129
  Liverwort 118
  Monkey cup 161
  Moss leaf 119
  Spiral wrack 116
  Sweet chestnut leaf 136
  Tree fern 113
  Venus fly trap 160
  Water lily leaf 159
Midships fence 373
Midships section 392
Midwater current 297
Midway Gardens 495
Mid West single-rotor engine 411
Mid West twin-rotor engine 411
Mid West two-stroke engine 410
Miele washer-dryer 594, 595
Mihrab 488
Milan Cathedral 473
Milankovic 43
Milk snake 184
Milk teeth 246
Milky quartz 268, 271
Milky Way 14-15
  Northern stars 18
  Solar system 30
  Stars of southern skies 20
Mill 462, 464, 492
Millstone grit 60-61
Milne 41
Milton 35
Mimas 46
Mimosa 21
Mimulopsis solmsii 145
Minaret 488-489
Mineral-filled fault 60-61
Mineral-rich deposits 298
Minerals 268-269
  Carnivorous plants 160
  Epiphytes 162
  Fossils 278
  Mineral features 270-271
  Mineral resources 280-281
  Photosynthesis 138-139
  Wetland plants 158
  Xylem vessel 134
Mineral spicules 166
Mineral spring 273
Mineral wool 603
Minim 502
Minmi 95
Minor calyx 256
Minor coverts 188, 191
Mint 109
Mintaka 18
Miocene epoch
  Fossil record 279
  Geological timescale 57
Mira 19, 20
Mirach 19, 20
Miranda 48
Mirfak 19, 20
Mirzam 18, 21
Missile launcher 397
Mississipian period 56
Mississippi Delta 290-291
Mississippi-Missouri River 264
Mississippi River 291
Mist 306
Mistle thrush 190
Mistletoe 162
Mitochondrial crista 217
Mitochondrial sheath 259
Mitochondrion 217, 259
Mitral valve 251
Mixosaurus 57
Mizar 19
Mizzen backstay 378
Mizzen bitt 381
Mizzen course 379
Mizzen mast
  Dhow 376
  Iron paddlesteamer 392
  Junk 376
  Sailing warship 377
  Square-rigged ship 375
  Wooden sailing ship 378
Mizzen sail 375, 385
Mizzen shroud 378
Mizzen stay 378
Mizzen top 378
Mizzen topcastle 377
Mizzen topgallant sail 379
Mizzen topmast 377, 378
Mizzen topsail 379
Mizzen yard 376-377, 378
Moat 466-467
Mobile sculpture 452
Modeling 452
Modeling tools 454
Modem 576, 577
Moderator 314
Modern buildings 496-499
Modern engines 344-345
Modern humans 57
Modern jetliners 412-415
Modern military aircraft 420-421
Modern piston aero-engines 410-411
Mode switch 586
Modified cuticle 157
Modified lateral shoots 156
Modified leaflets 129
Modified leaves
  Barberry 130-131
  Cobra lily 160
  Dryland plants 156-157
  Everlasting pea 129
  Golden barrel cactus 156
  Pitcher development 161
  Spines 156
  Strawberry 128
Modified shoots 156
Modified stipules 128-129
Modillion
  Baroque church 479
  Neoclassical building 478
  Renaissance building 475
Moenave formation 276
Moenkopi formation 276
Moeritherium 104
Mohorovic discontinuity 39
Mohs scale 270-271
Molar tooth
  Arsinoitherium 104
  Australopithecus 107
  Bear 106, 194
  Chimpanzee 202
  Elephant 201
  Horse 105
  Human 246
  Hyaenodon 107
  Moeritherium 105
  Opossum 106
  Phiomia 105
  Toxodon 106
Mold 278
Molded bracket 484
Molded corbel 493
Molding 485
  Ancient Egyptian temple 458-459
  Asian building 490
  Baroque church 480-481
  Dome 486-487
  Gothic church 471-472
  Medieval building 466, 469
  Neoclassical building 479-480, 482
  Renaissance building 475-477
  Ship's shield 395
Molding tool 454
Molds 114
Molecular orbitals 308
Molecules 306, 308-309
Mollusks 176-177
  Belemnite 71
  Nautiloid 69
Molten bronze 454
Molten core 39
Molten rock
  Igneous and metamorphic rocks 274
  Matter 306
  Ocean floor 298
  Plate movements 58
  Rock cycle 266
  Volcanoes 272
Molting 171
Molybdate 269
Molybdenum 310
Mongooses 194
Monkey cup 161
Monkeys 202-203
Monitor
  Digital camera 580
Monoceros 18, 21
Monoclinal fold 60
Monocline 61
Monoclinic system 270
Monocoque chassis 363
Monocoque shell 348
Monocotyledonous petals 140, 143
Monocotyledonous sepals 126, 140, 143
Monocotyledons 126-127, 140-141, 143
Monodon monoceros 205
Monograptus convolutus 65
Monolithic shaft 463
Monoplanes 400-401, 402, 406
Monotremes 206-207
Montes Apenninus 40
Montes Cordillera 41
Montes Jura 40
Montes Rook 41
Monteverdi 35
Montgolfier brothers 398
Monument 470
Moon 40-41
  Objects in universe 11
  Solar eclipse 32
  Tides 296-297
Moonquake region 41
Moons
  Jupiter 44
  Mars 42
  Neptune 50
  Saturn 46
  Solar system 30
  Uranus 48
Mooring 386-387
Moorish arch 484
Moraine 286-287, 292-293
Moray eel 180
Mortar 432
Mortice 373
Mortise 486, 492
Morus nigra 130
Mosaic 450-451
  Islamic building 488-489
  Tools 450
Mosque 484, 488
Mosses 112, 114, 118-119
  Epiphytic 162
  Life-cycle 119
  Structure 119
Moth 168
Motherboard
  Digital camcorder 583
  Personal computer 567
Motherboard cable 578
Mother's milk 104
Motion 320-321
Motion sensor 579
Motocross motorcycle racing 368
Motor air intake 593
Motor assembly 574
Motorcycle chassis 362, 364-365
Motorcycle engines 366-367
Motorcycle racing 368
Motorcycles 362-363
Motorcycle sidecar 362, 369
Motor-driven bogie axle 326
Motor electronic control module (ECM) 355
Motor end plate 228, 239
Motorhead 592, 593
Motorized buses 332
Motor neuron 228, 239
Motor operating signal 330
Motor whaler 397
Motte 466
Mouchette 472
Mounds 286
Mountain bikes 358, 360
Mountain building 56, 58, 62-63
Mountain hollows 286
Mountain lake 288
Mountain ranges
  Earth's physical features 264
  Faults and folds 60
  Geological time 56
  Igneous and metamorphic rocks 274
  Mountain building 62
  Ocean floor 298
  Plate movements 59
Mountain ridge 295
Mountain ring 34
Mountains 62-63, 267
Mountain spring 288
Mounting bracket 590
Mounting bush 365
Mounting splines 366
Mouse 521, 566, 611
Mouse and collar 379
Mouth
  Barnacle 173
  Bony fish 180-181
  Cobra lily 160
  Cow 198
  Crayfish 173
  Dogfish 179
  Dolphin 204
  Elephant 200
  Frog 182
  Gorilla 203
  Horse 199
  Human 211, 212, 244-245, 248
  Jellyfish 167
  Kangaroo 204
  Lamprey 178
  Lizard 184
  Pitcher plant 161
  Rabbit 196
  Rat 196
  Sea anemone 166-167
  Seal 204
  Sea urchin 175
  Snail 177
  Spider 170
  Starfish 174-175
Mouth diffuser 430, 440
Mouthpiece
  Brass instruments 506
  Clarinet 508
  Tenor saxophone 509
  Trumpet 506
  Wind synthesizer 521
Movement
  Gas particles 307
  Objects 320
MP3 players 586
MRI scan
  Head 214
  Brain 236
Mt. Everest 264
Mu Andromedae 19
Muav limestone 277
Muccini brush 434
Mucosa 248
Mucosal gland 254
Mucous gland 177
Mucronate leaf apex 137
Mucus-secreting duodenal cells 217
Mud 267, 273
Mud crab 279
Mud flat 295
Mud pools 272-273
Mud river 298
Mulberry 130
Muliphen 21
Mullion
  Gothic church 470, 472-473
  Modern building 497-499
  Renaissance building 476
  Small-scale rock formation 60-61
  Twentieth-century building 494
Multicellular animals 56
Multicellular organisms 78
Multicellular soft-bodied animals 56
Multifoil 472
Multifunction display 573
Multigabled roof 492
Multiplait nylon 388
Multiplate clutch 364, 366
Multiple fruits 148-149
Multiplier reel 562
Multi-ply tire 416
Multipolar neuron 239
Multitouch interface 568
Mu Orionis 18
Mu Pegasi 19
Musa 'lacatan' 146
Muscari sp. 155
Musci 118
Muscle 226-229
  Abductor digiti minimus 231, 233
  Adductor longus 225
  Adductor magnus 227
  Adductor pollicis 231
  Abductor pollicis brevis 231
  Anal sphincter 249
  Arrector pili 235
  Cricothyroid 244-245
  Dilator 241
  Dorsal interosseous 233
  Energy system 315
  Extensor digitorum brevis 233
  Extensor hallucis brevis 233
  Flexor digitorum longus 233
  Flexor hallucis longus 233
  Flexor pollicis brevis 231
  Flexor retinaculum 231
  Genioglossus 245
  Geniohyoid 245
  Gluteus medius 225
  Gluteus minimus 225
  Hyoglossus 244
  Iliacus 225
  Inferior oblique 241
  Inferior rectus 241
  Intercostal 255
  Internal urethral sphincter 257
  Lateral rectus 240-241
  Levator palpebrae superioris 241
  Lumbrical 231
  Medial rectus 240-241
  Myohyoid 245
  Opponens digiti minimi 231
  Opponens pollicis 231
  Orbicularis oris 245
  Papillary 251
  Pectineus 225
  Peroneus brevis 233
  Peroneus longus 233
  Psoas major 225, 257
  Pyloric sphincter 249
  Soleus 233
  Sphincter 241
  Styloglossus 244
  Superior longitudinal 245
  Superior oblique 241
  Superior rectus 241
  Tensor tympani 243
  Thyrohyoid 244
  Tibialis anterior 233
  Tibialis posterior 233
  Urethral sphincter 257
  Vastus lateralis 225
  Vastus medialis 225
Muscovite 269
Muscular septum 176
Mushroom anchor 386
Mushroom coral 167
Mushrooms 114, 115
Music 514, 586
Musical Instrument Digital Interface (MIDI) system 520-521
Musical manuscript 502-503
Musical notation 502-503
Musical score 502-503, 505
Music gallery 477
Musicians 504
Music software 520
Muslim calendar 618
Mussels 176
Mussosaurus 68
Mutes 506-507
Muttaburrasaurus 97
Muzzle 199, 397
Mycelium 114-115
Mycorrhizal association 133
Myelin sheath 239
Mylar 384
Myocardium 250-251
Myofibril 228
Myohyoid muscle 245
Myometrium 260

N

Nail
  Corythosaurus 98
  Edmontonia 95

Elephant 90
Human 231
Iguanodon 96-97
Stegosaurus 92
Triceratops 102
Nair Al Zaurak 19, 20
Naismath, James 532
Namib Desert 265
Naos 461, 463, 485
Nape 188, 210
Napier Saber 24-cylinder engine 408
Naris
Anchisaurus 89
Ankylosaurus 94
Arsinoitherium 104
Australopithecus 108
Baryonyx 83
Brachiosaurus 91
Camarasaurus 91
Corythosaurus 98
Edmontonia 95
Eryops 80
Euoplocephalus 94
Homo erectus 108
Homo habilis 108
Homo sapiens 108
Hyaenodon 107
Iguanodon 96
Lambeosaurus 99
Moeritherium 105
Opossum 106
Panoplosaurus 94
Parasaurolophus 99
Plateosaurus 88
Protoceratops 102
Smilodon 107
Stegoceras 100-101
Stegosaurus 92
Styracosaurus 102
Triceratops 102-103
Tyrannosaurus 84
Narrow gauge track 331
Narwhal 205
Nasal bone
Ankylosaurus 94
Bear 194
Frog 183
Human 220-221
Lion 194
Panoplosaurus 94
Protoceratops 102
Toxodon 106
Nasal cavity
Chimpanzee 202
Domestic cat 195
Elephant 200
Human 245, 248
Rabbit 196
Nasal horn 104
Nasalis 229
Nasal passage 200
Nasal plug 205
Nasal septum 213, 221, 241
Nash 21
Nasion 221
Nasolacrimal duct 241
Nasopharynx 245
Natal cleft 210
Natal cocoon 24, 26
Native elements 268
Natural bridge 290
Natural elements 310
Natural fly 562
Natural forces 314
Natural glass 306
Natural gut strings 544
Natural lakes 292
Natural satellites 40
Natural sponge 438
Nautiloid mollusk 69
Fossil 65
Navajo Mountain 277
Navajo sandstone 276
Nave
Ancient Egyptian temple 458-459
Baroque church 479
Cathedral dome 484
Gothic church 470-473
Medieval church 468-469
Ship's wheel 390
Navel 211, 260
Nave plate 390
Navicular bone 232
Navigating bridge 394
Navigational aerial 423-424
Navigation area 577
Navigation buttons 577
Navigation camera (Navcam) 615
Navigation display 573
Navigation light 573
Navigator's cockpit 420
Navigator's seat 408
Navka 37
Nazea plate 59
Neanderthals 108
Neap tides 296-297
Nebulae 16-17
Cone 612
Galaxies 12-13
Great, Orion 613
Life of massive star 26
Milky Way 14-15
NGC 1566 (Seyfert galaxy) 13
Omega 613
Small stars 24
Structure of nebula 24
Neck
Acoustic guitar 512-513
Anchisaurus 89
Calligraphy character 445
Corythosaurus 98
Electric guitar 513
Golf club 547
Harp 511
Horse 199
Human 211, 224-225, 247, 258-259
Iguanodon 97
Pachycephalosaurus 100
Rat 196
Sauropodomorpha 88
Sculling oar 560
Stegoceras 101
Stegosaurus 92
Stringed instruments 510
Tenor saxophone 509
Theropod 84
Violin 510
Necking 381
Nectar 142, 160-161
Nectaries 141, 144-145 160-161
Needles
Bishop pine 124
Pine 124-125
Scots pine 122
Yew 123
Nefertiti Corona 37
Negative electric charge 316
Negative ions 308, 310
Neo-Baroque style 492-493
Neo-Byzantine style 492-493
Neoclassical style 478-483, 496
Neodymium 310
Neo-Gothic style 492-493
Neo-Greek style 492-493
Neon 35, 311
Nepenthes mirabilis 161
Nephron 256
Neptune 31, 50-51
Neptunides polychromus 12
Neptunium 311
Nerve
Ampullar 242
Bronchial 254
Cervical 238
Cochlear 243
Common peroneal 238
Cranial 238
Cutaneous 238
Deep peroneal 238
Digital 231
Femoral 238
Hypoglossal 244
Lingual 244
Lumbar 238
Median 238
Optic 240
Posterior tibial 238
Pudendal 238
Pulp 247
Radial 238
Sacral 238
Sciatic 238
Spinal 223, 238
Superficial peroneal 238
Superior laryngeal 244
Thoracic 238
Ulnar 231, 238
Vestibular 243
Vestibulocochlear 243
Nerve cell 217, 237, 239
Nerve cord 173
Nerve fiber 235
Nerve ring 175
Nervous system 176, 238-239
Nervous tissue 166
Netball 534-535
Network port 566
Neural spine
Arsinoitherium 104
Bony fish 180
Brachiosaurus 90
Eryops 81
Euoplocephalus 95
87
Iguanodon 96
Parasaurolophus 98
Plateosaurus 89
Stegoceras 100-101
Stegosaurus 93
Toxodon 106
Triceratops 102
Tuojiangosaurns 93
Tyrannosaurus 85
Neurofilament 239
Neuron 239
Neurotransmitter 239
Neutralization 312
Neutrino 22
Neutron 22, 28
Neutrons 308, 309, 310
Neutron stars 28-29, 26-27
New Guinea 265
New mail button 576
New Moon 41
News item summary 577
News reader window 577
New State Paper Office 482
Newton (N) 320
Newton, Isaac 320
Newton meter 320-321
Newton's Motion laws 320-321
Newts 182
New World monkeys 202-203
New Zealand 265, 272
Next/Previous track control 587
Next file button 577
Next key 568
NGC 1566 (Seyfert galaxy) 13
NGC 2997 (spiral galaxy) 12
NGC 4406 (elliptical galaxy) 11
NGC 4486 (elliptical galaxy) 12
NGC 5236 (spiral galaxy) 11
NGC 5754 (colliding galaxies) 9
NGC 6656 (globular cluster) 21
NGC 6822 (irregular galaxy) 11
Nib types 444
Niche
Ancient Roman building 462
Asian temple 491
Baroque church 480
Cathedral dome 487
Gothic church 471-472
Islamic building 488
Medieval building 467
Neoclassical building 482
Renaissance building 476
Nickel 37, 49, 281, 311
Nickel-iron 270
Nigella damascena 151
Nikon Coolpix S1000PJ 580-581
Nile crocodile 186
Nile River 264-265
Nimbostratus cloud 302
Nimbus cloud 302
Nineteenth-century buildings 479, 482, 492-493, 494
Ninth-century building 490
Nintendo 3DS 578
Nintendo Wii Fit Plus 579
Niobe Planitia 36, 37
Niobium 310
Nippers 450
Nipple
Human 211
Marsupials 206
Nissl body 239
Nitrate ions 312
Nitrates 160
Nitrogen
Atmospheric composition 301
Helix Nebula 17
Mars' atmosphere 43
Periodic table 311
Pluto's atmosphere 51
Venus' atmosphere 37
Nitrogen dioxide gas 312
Nobelium 311
Noble gases 310-311
Nock 548
Noctis Labryrinthus 42, 43
Nocturnal mammals 104
Node
Bamboo 131
Brassavola nodosa 162
Canadian pond weed 158-159
Couch grass 113
Dicotyledons 127
Horsetail 120
Ice-plant 129
Live-forever 129
Modern buildings 497
Rhizome 155
Rock stonecrop 128
Rose stem 130
Stems 134
Stolon 154
Strawberry 128
Node of Ranvier 228, 239
Nodule fields 299
Nodules 128
Noggin 602
Nonconformity 276
Non-drive end 317
Nonesuch House 467
Nonexplosive eruptions 272
Nonflowering plants 68
Nonmetals 310
Nonreturn valve 367
Nonskid tire 337
Nonslip flooring 573
North America
Appalachian Mountains 62
Cretaceous period 72-73
Earth's physical features 264
Jurassic period 70
Late Carboniferous period 66
Middle Ordivician period 64
Quaternary period 76-77
Tertiary period 74-75
Triassic period 68
North American Cordillera 71
North American period 56
North American plate 59
North Atlantic current 296
North Atlantic Gyre 296
North Atlantic Ocean 39, 71, 73
North East Africa 64
Northeasterly wind 303
Northeast monsoon 297
Northeast trade winds 300
North Equatorial Belt 45
North Equatorial current 296-297
Northern Hemisphere 296-297
North Galactic Pole 15
North magnetic polar region 28
North Pacific current 296
North Pacific Gyre 296
North polar aurora 45
North polar ice cap 43
North Pole
Atmospheric circulation and winds 300
Coriolis force 297
Jupiter 44
Mars 42
Mercury 34
The Moon 40
Neptune 50
Pluto 51
Pulsar 28
Saturn 46
Uranus 48
Venus 36
North rim 277
North Temperate Zone 45
North Tropical Zone 45
Northwesterly wind 303
Nose
B-17 bomber 408
Concorde, the 416-417
Iron 594
Horse 198
Human 211-212, 244-245
Lion 194
Lockheed Electra airliner 406
Rabbit 196
Rat 196
Noseband 554, 555
Nose clip 558
Nose cone 418, 560
Nose cover 357
Nose cowling 412
Nose-end bogie 327
Nose-gear
ARV light aircraft 424-425
Concorde, the 417
Tornado 420
Nose horn 102, 103
Nose landing gear 573
Nose ring
Avro biplane 403
Blackburn monoplane 400
Nose wheel
ARV light aircraft 425
Curtiss biplane 398
Pegasus XL SE
Tornado 420
ultralight 426
Nostril
Bird 188
Chick 193
Crocodilians 186
Dolphin 205
Domestic cat 195
Elephant 200
Frog 182
Gorilla 203
Horse 198
Human 213
Kangaroo 207
Lion 194
Lizard 184
Monkey 202
Rat 196
Rattlesnake 185
Seal 204
Nostril pocket 80
Notes 502, 506
Nothosaurian reptile 69
Notre Dame de Paris 470, 473
Nozzle
Concorde, the 416-417
Jet engines 418-419
Tornado 421
Vacuum cleaner 593
NPT 301 turbojet 418
N-type silicon 605
Nu Andromedae 19
Nucellus 147
Nuchal plate 187
Nuchal ring 95
Nuchal shield 187
Nuclear energy 314
Nuclear fusion
Massive stars 26
Small stars 24
Stars 22
Sun 32
Nuclear "hunter-killer" submarine 396-397
Nuclear power station 314
Nuclear reactions 315
Nucleolus 216, 239
Nucleoplasm 216
Nucleus
Asteroids, comets, and meteoroids 52-53
Atoms and molecules 308, 309
Chlamydomonas sp. 116
Cnidocytes 167
Egg cell 606, 607
Endosperm 147
Fungal cell 115
Galaxies 12-13
Generalized human cell 216
Muscle cell 228
Neuron 239
Overhead view of our galaxy 14
Palisade mesophyll cell 139
Pollen 122
Pollen tube 147
Roots 132
Scots pine pollen 122
Side view of our galaxy 14
Synergid 147
Thalassiosira sp. 116
Nuctenea umbratica 171
Number systems 620
Nunki 19, 20-21
Nu Orionis 18
Nut
Deadeye 383
Dry fruit 150

Durmast oak 131
Toaster 598
Nutcrackers 321
Nutlets 150
Nutrients
Carnivorous plants 160
Epiphyte supply 162
Phloem sieve tube 134
Plant transport 139
Nylon and silicon cloth 384
Nymphaea sp. 159
Nyssa sylvatica 137

O

O_2 sensor 353
Oak 74
Oar
Greek and Roman ships 372-373
Junk 376
Longboat 380
Viking ships 374-375
Oarweed 116-117
Oasis 283
Oberon 48
Ob-Irtysh River 265
Objective aperture 610
Objective lens 610, 611
Object mass 320
Oblique-slip fault 61
Oboe 504-505, 508
Obovate leaves 137
Observer's cockpit 405
Observer's windshield 404
Obsidian 275, 306
Obstruction light 572
Obturator canal 224
Obturator membrane 224
Occipital bone 202, 220
Occipital condyle 107, 194, 220
Occipital lobe 236-237
Occipital region 106
Occluded fronts 302-303
Ocean currents 296-297
Ocean floor 298-299, 266-267
Oceanic crust
Earth's crust 58-59
Mineralization zones 281
Mountain building 62-63
Ocean floor 298
Oceanic seahorse 180
Ocean ridges 58-59
Oceans 39, 296-297, 301
Ocean trenches
Ocean floor features 299
Offshore currents 296
Plate movements 58
Oceanus Procellarum 40
Ocellus 176
Octafoil 471
Octagon 622
Octahedron 623
Octastyle portico 462
Octave 557
Octopus 176-177
Ocular end 377
Oculus
Ancient Roman building 462-463
Gothic church 472-473
Medieval building 466, 469
Neoclassical building 483
Roman corbita 372
Odd-toed ungulates 198-199
Odontoblast 247
Oeil-de-boeuf window
Baroque church 479, 481
Cathedral dome 487
Oerlikon gun position 397
Off-road motorcycle racing 368
Offshore deposits 294
Ogee 395
Ogee arch 488
Ogee-arched motif 490
Ogee curve 472
Ogee-curved dome 486
Ogee-curved roof 489
Ogee molding 475-477, 481
Ogee tracery 493
Ohms 316
Oil
Clutches 366
Diesel trains 326
Energy storage 315
Mineral resources 280-281
Oil bottle dripfeed 336
Oil cooler 347, 364, 605
Oil-cooler duct 415
Oil cooler matrix 347
Oil deposit formation 57
Oil deposits 281
Oil dipstick 344
Oil duct 151
Oil feed 411
Oil feed pipe 345, 366, 367
Oil filter
1-liter VTEC engine 354
Ford diesel engine 347
Jaguar V12 engine 345
Turbofan engine 418
Turboprop engine 419
Oil-fired power station 315
Oil formation 280-281
Oil muffler 364
Oil paints 436-437
Oil pipe banjo 345
Oil-pressure regulating valve 419
Oil pump
Humber engine 343
Mid West single-rotor engine 411
Velocette OHV engine 367
Weslake speedway bike 369
Oil rig 315
Oil side lamp 336-337
Oil sump
Honda VF750 364
Humber engine 343
Modern engines 344-345
Velocette OHV engine 367
Oil tank
Bell-47 helicopter components 422
Harley-Davidson FLHS Electra Glide 363
Lockheed Electra airliner 406
Turbofan engine 418
Turboprop engine 419
Oil traps 281
Oldsmobile 336-337
Old World monkeys 202-203
Olecranon 85
Olenellus 64
Oleo lock-jack 414
Olfactory bulb 181
Oligocene epoch
Fossil record 279
Geological timescale 57
Olivine
Igneous rock 267
Meteorites 52
Silicates 269
Olivine gabbro 275
Olympus BX51W1 optical microscope 610
Olympus Mons 42-43
Omasum 198
Omega Centauri 21
Omicron Andromedae 19
Omicronl Canis Majoris 21
Omicron2 Canis Majoris 21
Omicron Orionis 18
Omicron Sagittarii 21
Omnivores 84
Omohyoid muscle 229
Onboard information panel 573
One-toed ungulates 198
Onion dome 467, 486-488
Onion-skin weathering 282
On/off/pause button 586
On-screen display 577
Onyx 268
Oocyte 258
Oogonium 117
Oort Cloud 30, 52
Oospheres 116-117
Fern 121
Moss 119
Ooze 298
Open cluster 16
Open gun mounting 394
Opera House, Paris 493
Opera House, Sydney 496, 499
Opercula 180
Opercular bone 181
Operculum
Bony fish 180-181
Cnidocyte 167
Giant stick insect eggs 192
Indian stick insect eggs 192
Leaf insect eggs 192
Moss 119
Ophidia 184
Ophiothix fragilis 175
Ophiuchus 19, 20
Ophthalmos 372
Opisthodomos 461
Opisthosoma 170-171
Opossums 206, 207
Opponens digiti minimi muscle 231
Opponens pollicis muscle 231
Opportunity 615
Optical drive 567
Optical map of our galaxy 14-15
Optical microscope 610
Optic chiasma 236
Optic disk 240-241
Optic nerve 240
Option connector 571
Opus incertum 463, 465
Opus quadratum 465
Opus sectile mosaic 488-489
Oral arm 167
Oral cavity 248
Oral disk 166-167
Oral surface 175
Orange citrine 271
Orange halite 269, 277
Orange light 318
Orangutans 202
Ora serrata 241
Orb 486
Baroque church 480
Cathedral dome 487
Gothic church 471
Neoclassical building 479
Nineteenth-century building 493
Renaissance building 477
Orbicularis oculi muscle 226, 229
Orbicularis oris muscle 228-229, 245
Orbicular lamina 158
Orbicular leaves 137
Orbit
Acanthostega 80
Ankylosaurus 94
Archaeopteryx 85
Arsinoitherium 104
Australopithecus 108
Baryonyx 83
Bear 194
Bird 189
Bony fish 181
Camarasaurus 91
Chimpanzee 202
Diplodocus 90
Elephant 201
Eryops 80
Euoplocephalus 94
Heterodontosaurus 83
Homo erectus 108
Homo habilis 108
Homo sapiens 108
Horse 199
Hyaenodon 107
Iguanodon 96
Inner planetary 30
Lambeosaurus 99
Lion 194
Lizard 184
Opossum 106
Outer planetary 31
Pachycephalosaurus 100
Panoplosaurus 94
Parasaurolophus 99
Plateosaurus 88
Platypus 206
Prenocephale 100
Protoceratops 102
Rattlesnake 185
Rhesus monkey 202
Smilodon 107
Stars of northern skies 18
Stars of southern skies 20
Stegoceras 100-101
Styracosaurus 102
Toxodon 106
Triceratops 103
Tyrannosaurus 84
Orbital artery 179
Orbital cavity 220
Orbital motion 31, 52
Orbital plane
Earth 38
Jupiter 44
Mars 42
Mercury 34
Neptune 50
Pluto 51
Saturn 46
The Moon 40
Uranus 48
Venus 36
Orbitals 308-309, 310
Orbital speed (velocity)
Mercury 34
Solar system 30-31
Orb spider 171
Orchestra layout 504-505
Orchestral instruments 504-505
Musical notation 502-503
Orchestras 504-505
Orchestra shell 495
Orchids 126, 133, 162
Orcinus orca 205
Ordovician period 64-65
Fossil record 279
Geological time 56
Primitive life 78
Organ 514, 502-503
Organic compound 313
Organic material deposition 281
Organic remains 276-277, 280
Organ of Corti 243
Oriel window 467
"O Ring" drive chain 366
Orion 18, 21, 24
Orion Arm 14
Orion Nebula 15, 17, 18
Orion's belt 15-16
Ornament
Asian building 491
Baroque church 479, 481
Cathedral dome 487
Islamic building 488
Neoclassical building 483
Ornithischia 68-69, 82-83
Marginocephalians 100
Ornithopods 96
Stegosaurs 92-93
Thyreophorans 92
Ornithomimosaurs 86-87
Ornithopoda 83
Ornithopods 96-97, 98-99
Ornithorhynchus anatinus 207
Orobanche sp. 163
Orogenesis 62-63
Oropharynx 245
Orpiment 270-271
Orthoclase 269, 271
Orthorhombic system 270
Os 258-259
Oscillating cylinder 390
Oscillating electric field 318
Oscillating magnetic field 318
Oscillating steam engine 390-391
Osculum 166
Osmium 311
Ossicles 79, 174
Ossicles of middle ear 242
Osteichthyes 180
Osteocyte 225
Osteolaemus tetraspis 82
Osteon 225
Ostiole 117
Ostium
Crayfish 173
Sea anemone 167
Spider 170
Sponge 166
Ostrich 188, 193
Otters 194
Otto cycle 342
Otto, Nikolaus 342
Ouranosaurus 97
Outboard ammunition-feed blister 409
Outboard elevon 421
Outer bud scale 134
Outer casing fitment 597
Outer core 38-39, 41
Outer ear
Brachiosaurus 91
Stegoceras 101
Stegosaurus 92
Outer electrons 310-311
Outer envelope 25-26
Outer fertilized floret 142
Outer jib downhaul 385
Outer jib halyard 385
Outer jib sheet 385
Outer jib stay 382
Outer lamella 225
Outer mantle
Jupiter 44-45
Saturn 46-47
Outer tepals
Glory lily 143
Lily 140
Monocotyledons 126
Outfield 536
Outlet manifold 411
Output tray 574
Outrigger 373, 377
Outwash fan 286
Outwash plain 287
Outwash terrace 286
Ovary
Barnacle 173
Bony fish 181
Brachiosaurus 90
Butterfly 169
Chimpanzee 202
Crayfish 173
Dogfish 179
Epigeal germination 153
Fertilization 146-147
Flower 140-143
Gallimimus 86
Human 258-259
Hypogeal germination 152
Insect pollination 144
Lizard 185
Rose 131
Spider 170
Succulent fruit 148-149
Tortoise 188
Ovate leaf
Ice-plant 129
Live-forever 129
Strawberry 128
Ovda Regio 36, 37
Oven compartment 597
Overarm pass 535
Overhand knot 388
Overhand serve 534
Overhead camshaft engine 368
Overhead control panel 573
Overhead pass 532
Overhead valve engine (OHV) 367, 369
Over-reach boot 555
Overs 538
Oversailing fascia 477, 482, 486
Overthrust fold 61
Overturned fold 61
Overwing emergency exit 572
Oviduct
Barnacle 173
Brachiosaurus 90
Butterfly 169
Crayfish 173
Dogfish 179
Lizard 185
Spider 170
Tortoise 187
Ovolo 486
Ovolo molding
Cathedral dome 487
Gothic church 472
Neoclassical building 480
Ovotestis 177
Ovules 140-143
Bishop pine 124
Dehiscent fruit 151
Fertilization 146
Pine 122
Scots pine 122
Smooth cypress 123
Yew 123
Ovuliferous scales
Bishop pine 124
Pine 122
Scots pine 122
Smooth cypress 123
Yew 123
Ovum
Ancient Roman building 462
Fertilization 146-147
Scots pine 122
Oxalis sp. 157
Oxbow lake 293

River features 290
River's stages 289
"Ox-eye" window
Baroque church 479, 481
Cathedral dome 487
Oxides 268
Oxygen
Atmospheric
Atom 596
Composition 301
Early microorganisms 78
Earth's composition 39
Earth's crust 58
Earth's formation 38, 64
Helix Nebula 17
Mars' atmosphere 43
Mercury's atmosphere 35
Periodic table 311
Photosynthesis 138
Seed germination 152
Structure of red supergiant 26
Respiration 255
Oxygenated blood 255
Oxygen bottle 408
Oxygen group 311
Oyashio current 297
Oyster fungus 114
Oysters 176
Ozone 64
Ozone layer 300

P

Pachycephalosaurus 69, 85, 100
Pachypteris sp. 68
Pachyrhinosaurus 103
Pacific coastline 295
Pacific Ocean 264-265, 272
Pacific plate 59
Pacing races 554
Pacing sulky 554-555
Pacinian corpuscle 234-235
Pack-ice 296
Packing tissue
Dicotyledon leaf 126
Fern rachis 121
Golden barrel cactus 156
Haworthia truncata 157
Horsetail stem 120
Leaf succulents 157
Lithops bromfieldii 157
Monocotyledon leaf 126
Roots 132-133
Stem 134-135
Stem succulents 156
String of hearts 157
Water lily leaf 159
Padded coaming
Avro biplane 403
BE 2B bomber 404
Paddle
Eurypterid fossil 79
Kayak 560
Paddlesteamer
19th century 390-391
Iron 392-393
Paddle wheels 390-391, 392
Padmakosa 489
Page key 590
Page locator 577
Pagoda 490
Pahoehoe 272
Painted Desert 277
Painting knives 436, 442
Painting tools 442
Pair-cast cylinder 343
Paired cylinder 342
Palace of Westminster 492-493
Palais de Fontainebleau 476
Palais de Versailles 482
Palatine Chapel
Aix-le-Chapelle 484
Palatine tonsil 212, 244-245
Palatoglossal arch 244
Palazzo Stanga 482
Palazzo Strozzi 474-475
Pale calcite 26
Pale feldspar 26
Paleocene epoch
Fossil record 279
Geological timescale 57
Paleontology 278
Paleozoic era
Fossil record 279
Geological time 56
Palette 143, 436
Palette knife 436
Paling 466, 477
Palisade mesophyll 126, 159
Palladium 311
Palm
Danforth anchor 386
Hand 211
Roman anchor 372
Sailmaker's 384
Tertiary plant 74
Palmar arch 253
Palmaris longus tendon 231
Palmar vein 253
Palmate leaves 130, 136
Palmate venation 129
Palmette 460-461, 479-480
Palmoxylon 74
Pamirs 265
Pampas 264
Panavia Tornado GR1A 420-421
Pancam mast assembly 615
Pancreas
Bird 189
Bony fish 181
Chimpanzee 202
Dogfish 179
Domestic cat 195
Frog 182
Human 215, 249
Rabbit 196
Tortoise 187
Pandas 194
Panduriform leaves 136
Pane 494
Panel 485
Asian building 491
Baroque church 479-481
Cathedral dome 487
Gothic building 473
Islamic building 488
Medieval building 466, 469
Modern building 496-498
Neoclassical building 478-479
Nineteenth-century building 493
Renaissance building 475
Twentieth-century building 494
Panel board connector 570
Pangaea 66, 68-69, 70
Panniers 360, 361, 362
Panoplosaurus 94
Panicle 131
Panoramic camera (Pancam) 615
Pantheon 462-463
Pantile 464, 482
Pantograph 328, 330
Pan troglodytes 202
Paper
Acrylic paint 442
Calligraphy 444, 445
Pastels 440
Printing processes 446, 447
Watercolors 438
Paper feed components 575
Paper hopper 574
Paper output stacker 574
Paper stumps 440
Paper support 575
Papilla
Flower 140
Hair 235
Renal 256
Tongue 244
Papillary muscle 251
Pappus 142
Papyriform column 459
Parabellum machine-gun 405
Parabolic dune 283
Paraboloid roof 496, 499
Parachute seed dispersal 150
Paradise palm 126
Paragaster 166
Parallel dunes 283
Parallelogram 622
Parallel river drainage 288
Parallel shaft 382
Parallel venation 126
Parana River 264
Parapet
Ancient Roman building 465
Asian building 491
Baroque church 481
Dome 486
Gothic church 470-472
Islamic tomb 489
Medieval building 467
Neoclassical building 478, 483
Nineteenth-century building 493
Twentieth-century building 494
Parapet rail 483
Paraphysis 117, 119
Parasaurolophus 98-99
Parasitic anemone 166
Parasitic cone 272-273
Parasitic plants 162-163
Parasitic volcano 275
Paraxeiresia 373
Parceling 388
Parchment
Gilding 432
Imitation 445
Pareiasaur 81
Parenchyma
Dicotyledon leaf 126
Dryland plants 156-157
Fern rachis 121
Golden barrel cactus 156
Horsetail stem 120
Monocotyledon leaf 126
Pine stem 125
Roots 132
Stems 134-135
Water lily leaf 159
Parent plant 154
Parietal bone
Bony fish 181
Chimpanzee 202
Human 220-221
Parietal fenestra 102
Parietal lobe 236-237
Parieto-occipital sulcus 236-237
Parietosquamosal frill 102-103
Paripteris 66
Paris Metro 328
Paroccipital process
Iguanodon 96
Plateosaurus 88
Parrel
Dhow 376
Longboat 380
Sailing warship 377
Viking karv 375
Parrel beads 384
Parrel tackle 376
Parthenon 461
Partial solar eclipse 32
Partial veil 115
Particle attraction 307
Particle properties 318
Passiflora caerulea 130
Passing brace 473
Passion flower 130
Passive stack vents 602
Pastels 440-441
Pastern 198-199, 554
Pasteur 41
Patagonia 264
Patella
Domestic cat 195
Elephant 201
Hare 197
Horse 199
Human 219
Platypus 206
Rhesus monkey 202
Scorpion 170
Spider 171
Patellar surface 225
Patera
Neoclassical building 480
Renaissance building 476
Pause/play control 577
Paved floor 492
Pavilion 489, 495
Paving slab 499
Pavlova 37
Pavlovia 278
Pavo 20
Pavonis Mons 43
Paw 195
Pawl 380
Pawl slot 387
Paxton, J. 492-493
Pazzi Chapel 475
PCB *see* printed circuit board (PCB)
PC card adapter 574
PCs 566
PDAs 568, 588
Pea
Dry fruit 150
Danforth anchor 386
Peach 131, 148
Peacock 20
Peak halyard 380
Peat 280
Peccaries 198
Pecopteris 66
Pectineus muscle 225-226
Pectoral fin
Bony fish 180-181
Lamprey 178
Pectoral fin ray 181
Pectoralis major muscle 226
Pedal board 514
Pedal cluster 340
Pedal disc 167
Pedal-driven bicycle 358
Pedal gland 177
Pedalia 372
Pedals
Bass drum 518
Bicycle 320, 358-359
Eddy Merckx racing bicycle 360
Harp 511
Hi-hat cymbal 518
Piano 514
Rossin Italian time-trial bicycle 361
Pedal-muffler bar mechanism 516
Pedal stop 514
Pedestal
Ancient Roman building 462
Baroque church 480-481
Dome 484, 486-487
French temple 485
Harp 511
Neoclassical building 479
Renaissance building 476
Pedice 168
Pedicel
Brassavola nodosa 162
Clematis 131
Dicotyledon flower 127
Dry fruit 150-151
Fertilization 146-147
Florists' chrysanthemum 129
Flowers 140-141, 143
Fruit development 146-147
Oxalis sp. 157
Pitcher plant 113
Rose 131
Rowan 131
Russian vine 131
Succulent fruit 148-149
Sycamore 131
Vegetative reproduction 154
Water lily 159
Pedicle of vertebra 223
Pedicle valve 278
Pediment
Ancient Greek building 460
Ancient Roman building 462-463
Baroque church 480-481
Neo-Baroque building 493
Neoclassical building 478
Renaissance building 476
Pedipalp 170-171
Peduncle 140, 142-143
Aechmea miniata 162
Brassavola nodosa 162
Everlasting pea 129
Florists' chrysanthemum 129
Indehiscent fruit 150
Peach 131
Peruvian lily 129
Rowan 131
Russian vine 131
Succulent fruit 148-149
Toadflax 129
Vegetative reproduction 154
Wind-pollinated plant 144
Peephole 412, 414
Pegasus 19, 20
Pegasus Quasar ultralight 426-427
Pegasus XL SE ultralight 427
Peg-box 510-511
Pegmatite 26
Peg of vertebra 222
Pelagic clay 299
Pelecypoda 176
Peloneustes philarcus 71
Pelota 540
Pelvetia canaliculata 116
Pelvic fin
Bony fish 180-181
Dogfish 179
Pelvis
Bird 189
Bony fish 181
Dinosaur 81
Domestic cat 195
Elephant 201
Hare 197
Horse 199
Human 256, 258, 259
Kangaroo 206
Lizard 184
Platypus 206
Rhesus monkey 202
Seal 204
Turtle 187
Penalty area 524
Penalty box 524
Penalty kick 530
Penalty spot 529, 540
Pencils 430
Pencil sharpener 430
Pencil slate sea urchin 175
Pendentive 479, 484, 488
Penguins 188
Penis
Barnacle 173
Dolphin 205
Human 211, 259
Snail 177
Pennant number 397
Pennsylvanian period 56
Penny washer 383
Pens 430
Penstock 314
Pentagon 622
Pentaradiate symmetry 174
Pentroof 490
Penumbra 32
Pepo 149
Pepper-pot lantern 481
Perch 180
Percolation 280
Percussion instruments 516-517
Drums 518-519
Electronic 520
Orchestral arrangement 504-505
Perennials 128, 130-131
Pereopod 172-173
Perforated shroud 592
Perianth 140
Pericardial cavity 250
Pericarp 148
Dry fruit 150-151
Embryo development 147
Fruit development 146-147
Succulent fruit 148-149
Sycamore 131
Pericranium 237
Pericycle 127, 132
Periderm 125
Peridium 115
Perihelion 30-31
Perimeters 622
Perineum 258
Periodic table 310-311
Periodontal ligament 247
Periodontium 247
Periosteum 225
Peripheral nervous system 238
Peripteral temple 460-461
Periscope 396, 397
Perissodactyla 104, 198-199
Peristome tooth 119
Peristyle 461
Peritoneum 249, 257
Permeable limestone
Caves 284-285
Lake formation 292
Permeable rock 292
Permeable sandstone 292

Permian period 66-67
  Fossil record 279
  Geological time 57
Peroneal artery 253
Peroneus brevis muscle 227, 233
Peroneus brevis tendon 233
Peroneus longus muscle 233
Peroxisome 217
Perseus 19, 20
Perseus Arm 14-15
Persian ivy 137
Personal computer 566-567
Personal digital assistants (PDAs) 568
Personalized mail folder 576
Personal lighting 572
Personal music and video 586-587
Perspective drawing 431
Peru current 296
Peruvian lily 129
Petal molding 480
Petals 140-143
  Clematis 131
  Color 140, 144-145
  Dicotyledons 126-127
  Everlasting pea 129
  Fertilization 146
  Insect pollination 145
  Monocotyledons 126
  Peruvian lily 129
  Rose 131
  Water lily 159
Petavius 40
Petiole 128, 136-137
  Chusan palm 130
  Clematis 131
  Cobra lily 160
  Dicotyledons 127
  Everlasting pea 129
  Florists' chrysanthemum 129
  Horse chestnut 130
  Kedrostis africana 113
  Maidenhair tree 123
  Monocotyledons 126-127
  Mulberry 130
  Oxalis sp. 157
  Passion flower 130
  Peach 131
  Rock slonecrop 128
  Seedling 153
  Strawberry 128
  String of hearts 157
  Tree fern 112
  Tree mallow 131
  Vegetative reproduction 154
  Venus fly trap 160
  Water Inacinth 158
  Water lily 159
  Wind-pollinated plant 144
Petiolule 137
Petrol 315
Peugeot, Armand 334
Phacops 64
Phaeophyta 16
Phaet 21
Phalaenopsis sp. 126
Phalanges
  Cow 198
  Crocodile 186
  Diplodocus 90
  Domestic cat 195
  Elephant 90
  Eryops 80-81
  Frog 183
  Hare 197
  Horse 198-199
  Kangaroo 206
  Lizard 184
  Parasaurolophus 99
  Plateosaurus 88
  Platypus 206
  Rhesus monkey 202
  Seal 204
  Stegoceras 100-101
  Triceratops 102-103
  Turtle 187
  Tyrannosaurus 84
Phalanx
  African elephant 201
  Archaeopteryx 85
  Arsinoitherium 104
  Baryonyx 85, 87
  Horse 105
  Human 219, 230
  Plateosaurus 88
  Stegoceras 100
  Struthiomimus 87
  Toxodon 107
Phallus impudicus 114
Phanerozoic eon 279
Pharyngeal tubercle 220
Pharynx
  Bony fish 180-181
  Dogfish 179
  Human 212, 244
  Sea anemone 167
  Sea urchin 175
Phascolarctos cinereus 207
Phaseolus sp. 153
Phases of the Moon 41
Phekda 19
Phellem
  Pine root 125
  Stem 134-135
  Woody dicotyledon 127
Phi Andromedae 19
Phidias 35
Philippine plate 59
Phillips, Horatio 402
Philoxenus 35
Philtral ridge 213
Philtrum 213
Phiomia 104
Phloem 138
  Bishop pine 124-125
  Clubmoss stem 120
  Dicotyledons 126-127
  Dodder host 163
  Epiphytic orchid 162
  Fern rachis 121
  Horsetail stem 120
  Marram grass 113
  Monocotyledons 126-127
  Parasite host 163
  Photosynthesis 138
  Pine root/stem 125
  Radicle 152
  Root 132-133
  Sieve tube 134
  Stem 134-135
  Water hyacinth root 158
  Water lily leaf 159
Phloem fibers 134-135
Phloem sieve tube 134
Phobos 42
Phoebe Regio 36
Phoenicopterus ruber 190
Phoenix 19, 20
Phorusrhacos 74
Phosphates 269
Phosphate/sugar band 216
Phosphor imaging screen 611
Phosphor lining cell 584
Phosphorus 311
Photomicrographs of skin and hair 235
Photons 318
Photo print button 570
Photo select button 575
Photosphere 32-33
Photosynthesis 112, 116, 134, 136, 138-139
  Carnivorous plants 160-161
  Organelle 116, 139
Photosynthetic cells 139
  Bishop pine 124
  Coconut palm stem 135
  Water lily leaf 159
Photosynthetic region 157
Photosynthetic tissue
  Cacti 156
  Dicotyledon leaf 126
  Horsetail stem 120
  Marram grass 113
  Monocotyledon leaf 126
  Rush stem 135
Photovoltaic cell 603
Photovoltaic panel 603
Phyla 116
Phyllode 160
Phylum 116
Physalis peruviana 149
Physeter catodon 205
Physical weathering 282
Physics symbols 621
Pi2 Orionis 18
Pi3 Orionis 18
Pi4 Orionis 18
Pi5 Orionis 18
Pi6 Orionis 18
Pia mater 237, 240
Piano 503, 514
Piano nobile 474, 494
Piano, R. 496
Piazza 474
Pi Canis Majoris 21
Piccolo 504, 508
Pictor 21
Pier 484
  Ancient Egyptian temple 459
  Ancient Roman building 465
  Baroque church 480
  Gothic church 470
  Medieval building 467-469
  Renaissance building 476-477
  Twentieth-century building 494-495
Pier buttress 469-471, 486
Pietra dura inlay 489
Piezoelectric inkjet printhead 575
Pigments 433, 434, 436
Pigs 104, 198
Pilaster
  74-gun ship 381
  Ancient Greek building 461
  Ancient Roman building 463-465
  Asian temple 490-491
  Baroque church 479-481
  Cathedral dome 484, 487
  Gothic church 471
  Neoclassical building 478, 483
  Renaissance building 476
Pileus 114-115
Pillar
  Asian buildings 490-491
  Domed roof 486
  Gothic church 472
  Ironclad 393
  Renaissance building 477
  Twin bollards 387
Pillow lava 298
Pilotis 494
Pilot light 594
Pilot's cockpit
  LVG CVI fighter 405
  Tornado 420
Pilot's cradle 398-399
Pilot's seat
  Airbus 380 573
  Avro biplane 402
  Curtiss biplane 398
  Pegasus Quasar ultralight 427
Pin
  Capstan 387
  Dome timbering 486
Pinacocyte 166
Pineal body 212, 236
Pine hull 373
Pines 122, 124-125
Pinguicula caudata 161
Pinion
  Benz Motorwagen 335
  Ford Model T 338
  Hand drill 601
Pinna
  Elephant 201
  Everlasting pea 129
  Fern 121
  Gorilla 203
  Human 242-243
  Kangaroo 207
  Leaves 136-137
  Rabbit 196
  Rat 196
  Sago palm 123
  Tree fern 112-113
Pinnacle
  Baroque church 479, 481
  Gothic church 470, 472-473
  Medieval church 469
  Nineteenth-century building 493
  Renaissance building 476
Pinnate leaves 136-137
  Mahonia 130-131
  Rowan 130
  Sago palm 123
Pinned sheepshank 389
Pinnipedia 204
Pinnule 121, 137
Pinocytotic vesicle 217
Pintle strap 378
Pinus muricata 72, 124-125
Pinus sp. 122, 124-125
Pinus sylvestris 122
Pi Pegasi 19
Pipette 312
Pips 148-149
Pi Sagittarii 21
Pisanosaurus 68
Pisces Austrinus 19, 20
Piscis 19, 20
Pisiform bone 230
Piste 556, 557
Pistol shooting 548
Piston
  Disc brake 365
  Early engines 342-343
  "Ellerman Lines" steam locomotive 325
  Ford diesel engine 347
  Mid West two-stroke engine 410
  Modern engines 344-345
  Relief-printing press 449
  Steam locomotive 324
  Two-stroke engine 366
  Velocette OHV engine 367
  Volkswagen Beetle 340
Piston engines 410-411, 424
Piston rod 324, 334, 390
Piston valves
  Brass instruments 506
  Cornet 507
  "Ellerman Lines" steam locomotive 325
  Flugelhorn 507
  Stringed instruments 510
  Trumpet 506
  Tuba 507
Pisum sativum 150
Pitatus 40
Pitch
  Brass instruments 506
  Drums 518
  Musical notation 502
  Percussion instruments 516
  Propeller action 390
  Screw thread angle 320
  Woodwind instruments 508
Pitched roof
  Ancient Roman building 462, 464
  Gothic church 471-472
  Medieval building 466-468
  Nineteenth-century building 492
  Renaissance building 476-477
  Twentieth-century building 495
Pitcher 536
Pitcher plants 113, 160-161
Pitches
  Australian rules football 528
  Baseball 536
  Cricket 538
  Gaelic football 529
  Lacrosse 540
Pitching wedge
  Baseball 537
  Golf 547
Pitfall traps 160
Pith
  Apical meristem 134
  Bishop pine stem 125
  Dicotyledon stem 127
  Epiphytic orchid 162
  Horsetail stem 120
  Monocotyledon root 127
  Pine stem 125
  Stems 134-135
Pith cavity 135
Pitot head
  ARV light aircraft 425
  BAe-146 jetliner components 412
  Bell-47 helicopter 422
  Concorde 416-417
  Hawker Tempest fighter 409
  LVG CVI fighter 405
  Schweizer helicopter 423
  Tornado 420
Pitot mast 407
Pituitary gland 212, 236
Pivot
  Astrolabe 377
  BAe-146 jetliner components 414
  Drum brake 365
  Sundial 377
  Viking ships 374-375
Pixel 570, 571
Place kick 530
Placenta
  Dry fruit 150-151
  Fern pinnule 121
  Human 260
  Succulent fruit 148-149
Placental mammals 74, 104
Placer deposits 280
Plagioclase feldspar 275
Plains viscacha 197
Planck 41
Plane shapes 622
Planetary nebula
  Nebulae and star clusters 17
  Small stars 24-25
Planetary rotation 30
Planets
  Jupiter 44-45
  Mars 42-43
  Mercury 34-35
  Neptune 50-51
  Pluto 50-51
  Saturn 46-47
  Solar system 30-31
  Uranus 48-49
  Venus 36-37
Planking
  Ironclad 393
  Longboat 380
  Roman corbita 373
  Sailing warship 377
  Tea clipper 392
Plantar calcaneonavicular ligament 252
Plant bodies 116
Plant capital 459
Plant-eating dinosaurs 68, 70
Plant matter 280
Plant remains
  Fossils 278-279
  Mineral resources 280
  Sedimentary rocks 276
Plants 56, 66
  Electromagnetic radiation 314
  Flowering 57, 70, 72
  Fossil record 279
  Non-flowering 68
Plant variety 112-113
Plasma 306
Plasma display 584
Plasma screen 584
Plaster 452, 464-465
Plasterboard 602
Plastic bumper 354
Plastic fletch 548
Plastic front wings 354
Plastic insulator 316, 317
Plastic rackets 544
Plastid 116
Platanus x acerifolia 134
Platband 481
Plate
  Etching press 477
  Motorcycle clutch 366
  "O Ring" drive chain 366
Plateau
  Neptune's rings 50
  Structure of Neptune 51
Plateaus 276-277
Plate boundaries 62, 273
Plate clip 587
Platelets 253
Plate movements 58-59
  Faults and folds 60
  Mountain building 62-63
Platen 449
Plateosaurus 69, 88-89
Plate tectonics 58-59
Platform
  Cathedral dome 487
  Early tram 332
  Medieval building 467-468
  Modern building 498
Platform diving 558
Platlorm stage 477
Platinum 311
Plat lesene 480
Plato 40
Platypus 206-207
Platysma 229
Playa 283
Play button 585
Player's bench
  Basketball 532
  Football 526
  Handball 535
  Ice hockey 550
  Volleyball 534
Play/pause control 577
Plaza 498
Pleiades 14, 16, 19, 20
Pleistocene epoch

Fossil record 279
Geological timescale 57
Pleistocene period 76
Plenum chamber 344-345
Plenum ring 418
Pleopod 172
Plesiochelys latiscutata 73
Plesiosaurs 70-71
Pleurotus pulmonarius 114
Plica circulare 249
Plicate lamina 127
Pliers 321
Plinth
Baroque church 480
French temple 485
Islamic tomb 489
Modern building 499
Neoclassical building 479, 483
Renaissance building 476
Twentieth-century building 494-495
Pliocene epoch
Fossil record 279
Geological timescale 57
Plough anchor 386
Plug-ins 521
Plug lead conduit 337
Plugs 272-273
Igneous rock structures 274
Plumage 188
Plume 45
Plumose anemone 166
Plumule 147, 152-153
Plunge 60
Plunge pool 289, 291
Pluto 31, 50-51
Plutonium 310-311
Plywood roof deck 603
Plywood skin 404
Pneumatic tires 358, 555
Podetium 114
Podium 463, 499
Point
Angling hook 562
Cricket 538
Double bass bow 511
Sailmaker's fid 384
Sculpting tool 452-453
Violin bow 510
Point bar
Mississippi Delta 291
River's stages 289
Pointed arch 466, 467, 469, 472
Pointed hog hair brush 454
Pointed riffler 454
Pointed sable brush 444
Pointing 383
Poison duct 170
Poison gland
Octopus 176
Spider 170
Polacanthus 95
Polar band 36
Polar body 606, 607
Polar bottom water 296
Polar easterlies 300
Polar fronts 302
Polar hood 36
Polaris 14, 18-19
Polar jet stream 300
Polar nuclei 146
Poles 297, 300
Pole star 14, 18
Pole vault 542
Polian vesicle 175
Political map of the world 616-617
Poll 199
Pollen 140, 142, 144-145
Dicotyledon flower 126
Fertilization 146-147
Pollen-forming structures 122
Pollen grains 144-145
Fertilization 146-147
Pine 122
Scots pine 122
Pollen sac wall 144
Pollen tubes
Fertilization 146-147
Scots pine 122
Pollination 144-145, 122
Pollux 18, 21
Polonium 311
Polycarbonate plastic bin 592
Polyester 388
Polygala chamaebuxus 144
Polygnotus 35
Polygonum baldschuanicum 131
Polyhedral dome 486-487
Polypropylene rope 388
Polythene 306
Polytrichum commune 119
Polyurethane insulation 603
Pome 131, 149
Pommel 554
Pond weeds 158
Pons 212, 236-237
Poop break 373
Poop deck
74-gun ship 381
Iron paddlesteamer 392
Roman corbita 373
Poop rail
74-gun ship 381
Wooden sailing ship 378
Poor metals 310-311
Popchu-Sa Temple 490
Popliteal artery 253
Popliteal fossa 210
Porch 470-471
Porcupines 196-197
Pore
Bishop pine needle 124
Blackberry 147
Dryland plants 156-157
Elder stem 130
Epigeal germination 153
False fruit 148
Gas exchange 138, 158
Golden barrel cactus 156
Haworthia truncata 157
Leaf 138-139
Liverwort 118
Monocotyledon leaf 126
Nuclear membrane 217
Perennial bark 130-131
Pollen grain 144-145
Seed 153
Sponge 166
Water absorption 150, 153
Wetland plants 158
Woody plants 130-131
Woody stems 134
Porifera 166
Porocyte 166
Porous limestone 284
Porous stipe 114
Porphyritic andesite 275
Porpoises 204
Porrima 21
Porsche, Ferdinand 340
Port
Trojan two-stroke engine 342
Wooden sailing ship 379
Portal 476, 480
Portal vein 252
Porta Nigra 462, 465
Port bower anchor 377, 395
Port foremast 376
Porthole
Battleship 394
Dome 487
Frigate 397
Portico
Ancient Greek building 460-461
Ancient Roman building 462-463
Neoclassical building 482-483
Renaissance building 475
Portugal 331
Portuguese bowline 388
Position guide 447
Positive electric charge 316
Positive ions 308, 310
Positive metal comb 316
Positive terminal 316, 317
Positron 22
Post 481, 486
Postabdominal spine 169
Postacetabular process 82
Postcentral gyrus 237
Post-crural musculature 90
Posterior antebrachial musculature 86, 91
Posterior aorta 170
Posterior arch 222
Posterior border of vomer 220
Posterior brachial muscle 86, 91
Posterior branch of spinal nerve 223
Posterior cerebral artery 252
Posterior chamber 241
Posterior chamber of cloaca 185
Posterior column 223
Posterior crural muscle 87
Posterior cuneonavicular ligament 232
Posterior dorsal fin
Bony fish 181
Dogfish 179
Lamprey 178
Posterior horn 223
Posterior nasal aperture 220
Posterior nasal spine 220
Posterior part of tongue 245
Posterior petal 141
Posterior root 223, 238
Posterior semicircular canal 243
Posterior sepal 141
Posterior tarsometatarsal ligament 232
Posterior tentacle 177
Posterior tibial artery 253
Posterior tibial nerve 238
Posterior tubercle 222
Posterior vena cava 182
Posterior wing of shell 176
Posterolateral horn 94
Post-glacial stream 286
Post-glacial valley 286
Post-modernism 296, 496
Post-motor micropore filter 592
Potassium 35, 58, 286, 310
Potassium chromate solution 312
Potassium dichromate ions 312
Potassium iodide 312-313
Potassium nitrate 313
Potassium permanganate 306
Potato 128
Potential energy 314, 315
Potholes 284
Pouch 206
Power bar 552
Power drill 600-601
Power button
Home cinema 585
Inkjet printer 574
Personal computer 566-567
Power levers 573
Power output 360, 366
Power/play/pause button 586
Power plug 591
Power stations 314, 315
Power steering belt 351
Power steering pump 344, 351
Power stroke 343
Power-to-weight ratio 328
Power transistor heat sink (dissipator) 585
Power transistors 585
Practice projectile 396
Pradakshina 491
Praesepe 18
Prairie style 495
Praseodymium 310
Pratt & Whitney Canada turbofan engine 418-419
Pratt & Whitney Canada turboprop engine 419
Pratt & Whitney radial engine 406-407
Praxiteles 35
Preacetabular process 82
Precambrian period 56, 64-65, 279
Precambrian seas 78
Precentral gyrus 237
Precious metals 311
Precipitate 312
Precipitation 288, 302-303
Predatory dinosaurs 84
Predatory theropods 88
Predentary bone
Arsinoitherium 104
Iguanodon 96
Lambeosaurus 99
Protoceratops 102
Triceratops 103
Prefix 577
Prehensile tail 202
Prehistoric foods 109
Pre-load adjustor 365
Premaxilla
Baryonyx 83
Arsinoitherium 104-105
Bony fish 181
Chimpanzee 202
Elephant 201
Frog 183
Iguanodon 96
Lambeosaurus 99
Premolars
Australopithecus 107
Bear 106, 194
Chimpanzee 202
Horse 105
Human 246
Lion 194
Prenocephale 100-101
Preopercular bone 181
Preparatory drawing 430-431
Prepubic process
Iguanodon 96
Parasaurolophus 98
Stegosaurus 93
Prepubis
Ornithischian 82
Stegoceras 100-101
Prepuce 259
Preserved remains 278
Press
Etching 447
Lithographic printing 446
Relief-printing 449
Pressed steel wheel 340
Pressure
Formation of black hole 29
Igneous and metamorphic rocks 274
Mineral resources 280
Stellar black hole 29
Volcanic features 273
Pressure line 418
Pressure plate 366
Pressurized cabin 406
Pressurized keel box 417
Pressurized strut 425
Pressurized water reactor 314
Presta valve 361
Presynaptic axon 239
Presynaptic membrane 239
Preview monitor slot 575
Preview monitor socket 574
Previous file button 577
Previous key 568
Previous/next track buttons 585
Previous track control 587
Prickers 383
Prickle
Blackberry 147
Bramble stem 130
Rose stem 130
Slender thistle 129
Primary bronchus 215
Primary colors 439
Primary-drive gear 366
Primary flight display 573
Primary flight feathers 188, 191
Primary follicle 258
Primary leaf 121
Primary mirror 612
Primary mirror housing 613
Primary mycelium 115
Primary remiges 188, 191
Primary root 132-133
Germination 152-153
Seedling 152-153
Primary teeth 246
Primary thallus 114
Primary xylem 125, 135
Primates 108, 202-203, 279
Primer 348, 436
Primitive crocodilians 68
Primitive life-forms 64
Primitive mammals 206
Principal arteries and veins 253
Principal rafter
Ancient Roman mill 464
Dome 486
Gothic building 473
Printer 574-575
Printer cover 574, 575
Printing block 449
Printing papers 447
Print making 446-447, 448-449
Prism 318, 623
Prismatic habit 271
Privy 380
Probactosaurus 97
Probes, space 614-615
Proboscidea 104
Proboscis 169, 201
Procambial strand 134
Procerus muscle 229
Processing cooling fan 567
Processing light 575
Processional path 470
Procompsognathus 87
Procoptodon 76
Procyon 8, 21
Procyon lotor 195
Production line
Mass-production 338
Modern bodywork 348
Modern trim 352
Programme display 577
Program name 577
Projectile 396
Projector assembly 581
Projector lens 611
Prokaryotes 78
Prolegs 169
Promethium 311
Prominence 32-33
Pronaos 461
Pro-otic bone 183
Propagative structures 154-155
Propellant 396
Propellant tank 615
Propeller 390-391
ARV light aircraft 425
Battleship 395
Biplanes and triplanes 402-403
Early monoplanes 400-401
Ford diesel engine 347
Frigate 396
Hawker Tempest components 408
Lockheed Electra airliner 406-407
Pegasus Quasar ultralight 427
Pioneers of flight 398-399
Submarine 396
World War I aircraft 404-405
Propeller-bolt collar 411
Propeller brake pad 419
Propeller drive flange
ARV light aircraft 425
Modern piston aero-engines 410-411
Propeller drive gearbox 427
Propeller drive shaft 408
Propeller-hub spinner 407
Propeller shaft
Brazilian battleship 395
Wright Flyer 399
Propeller shaft boss 395
Propeller-shaft bracing strut 398-399
Propeller shaft rear bearing 410
Propeller speed probe 419
Propeller spinner 408, 409
Propodus 172, 173
Propylaeum 460
Prosauropoda 85
Prosauropods 88
Proscapular process 187
Prosimians 203
Prosimii 202
Prosoma 170, 171
Prostate gland 257, 259
Prostyle colonnade 485
Protactinium 310
Protective clothing
Cricket 539
Football 528
Ice hockey 550-551
Protective eyewear 544
Protective gaiter 422
Protective outer layer 125
Protective root covering 153
Protective scale 134
Protective scale leaf 155
Protein body 112
Protein fibers 166
Protein matrix 166
Protein synthesis site 139
Proterozoic eon 279
Proteus 50
Prothallus 121
Prothorax 168
Protista 112, 116
Protoceratops 102-103

Protogalaxies 10-11
Proton 308, 316
  Atomic mass 310
  Atomic number 310
  Fluorine-19 309
  Nuclear fusion 22
Protonema 119
Protostar 24, 26
Protoxylem
  Dicotyledon root 127
  Monocotyledon root 127
  Root 132-133
Proventriculus
  Bird 189
  Crayfish 173
Prow 372, 375
Prowhead 374
Proxima Centauri 18
Proximal convoluted tubule 256-257
Proximal interphalangeal joint 231
Proximal phalanx 230, 232
Prunus persica 131
Psathyrella candolleana 115
Pseudocarps 148-149
Pseudo-Corinthian capital 476
Psi Sagittarii 21
Psittacosaurus 100, 103
Psoas major muscle 225, 257
Pterapsis 65
Pterichthyodes 65
Pteridium aquilinum 121
Pterois volitans 180
Pteron 460-461, 463
Pterosaurs 70-71
Pterygoid bone 183
Pterygoid hamulus 220
Pterygoid plate 220
Ptolemaeus 40
Ptolemaic-Roman period 459
"P" turret 395
P-type silicon 605
Pubic bone 261
Pubic ramus 257
Pubic symphysis 258
Pubis
  Archaeopteryx 85
  Bird 189
  Diplodocus 90
  Eryops 81
  Gallimimus 86
  Human 218, 224, 259
  Iguanodon 96
  Ornithischian 82
  Plateosaurus 88
  Saurischian 82
  Stegosaurus 93
  Struthiomimus 87
  Tyrannosaurus 84
Pubofemoral ligament 224
Pudenda 211
Pudendal nerve 238
Puffballs 114
Pugin, A.W.N. 493
Pull-down edit menu button 577
Pulley bolt 360
Pulley rim rear brake 362
Pulley wheel
  Simple pulleys 320
  Van de Graaff generator 316
Pulmonary artery
  Frog 182
  Human 251, 253, 254-255
Pulmonary semilunar valve 251
Pulmonary trunk 251, 255
Pulmonary vein 251, 253, 254
Pulp artery and vein 247
Pulp chamber 247
Pulp horn 247
Pulp nerve 247
Pulsar 28
Pumice 275
  Marble carving 453
Pump
  Nuclear power station 314
  Testing candle wax 313
Pump drive belt 410
Pump drive shaft 411
Pump piston 391
Pupa 168
Pupil
  Caiman 186
  Human 213, 226, 241
Pupil's cockpit 403
Puppis 18, 21
Purchase 382-383
Purchase wire 394
Pure substances 306
Purfling 510, 511
Purkinje's cells 237
Purlin 473
Pusher propeller
  Pegasus Quasar ultralight 426
  Pioneers of flight 398-399
Push moraine 286
Push-rod 365, 367
Putter 547
Putting green 546
Putto 476
Putty eraser 430, 440
"P" wave 63
Pygal shield 187
Pygostyle 189
Pylon 314
Pylon fairing 427
Pylon forward fairing 573
Pylon strut 427
Pyloric cecum
  Bony fish 181
  Starfish 174
Pyloric duct 174
Pyloric region of stomach 179
Pyloric sphincter muscle 249
Pyloric stomach 174
Pyramid 458, 623
Pyrenees 77, 265
Pyrenoid 112, 116
Pyrites 268
  Intrusive igneous rocks 275
Pyroclasts 272
Pyromorphite 269
Pyroxene 52, 267
Pyxis 18

Q

Quadrant arch 468
Quadrate bone 181
Quadratojugal bone
  Frog 183
  Heterodontosaurus 83
Quadrilateral 489
Quadripartite vault 469
Quadrupedal dinosaurs 88, 92, 96, 100
Quadruplanes 402
Quark 309
Quarter back 526
Quarterdeck 380-381
Quarterdeck house 376
Quarter gallery 381
Quarter glass 348
Quarter light 340-341
Quarter panel molding 352
Quarter trim panel 352
Quartz
  Color 271
  Metamorphic rock 267
  Oxides/hydroxides 268
Quasar (quasi-stellar object)
  Galaxies 12
  Objects in universe 11
  Origin and expansion of universe 10-11
Quasar nucleus 13
Quaternary period 57, 76-77
  Fossil record 279
Quatrefoil 471-473
Quaver 502
Quayside 387
Queen-post 473
Quercus palustris 74
Quercus petraea 131
Quick-release base 590
Quick-release mechanism 425
Quick-release strap 360
Quill
  Drill 601
  Feather 191
  Writing tool 444
Quinacridone red 442
Quit key 590
Quiver 548
Quoin
  Baroque church 481
  Medieval building 466
  Nineteenth-century building 492
  Renaissance building 476

R

Rabbit line 380
Rabbits 196-197
Raccoons 194-195
Race car 356-357
Raceme 129
Rachilla 137
Rachis 136-137
  Bipinnate leaf 137
  Couch grass 113
  Everlasting pea 129
  Feather 191
  Fern 121
  Hogweed 129
  Pinnate leaf 136-137
  Rowan leaf 130
  Tree fern 112
  Tripinnate leaf 137
Racing bicycle 360
Racing chain 361
Racing colors 554-555
Racing saddle 554
Racing sidecar 368-369
Racing "silks" 554-555
Racing tire 365
  Formula One race car 356-357
  Suzuki RGV500 368-369
Racketball 544-545
Racket sports 544-545
Radar
  Modern jetliners 412
  Modern military aircraft 420-421
  World War II aircraft 408
RADAR antenna 397
RADAR for gunnery and missile control 397
Radial artery 231, 253
Radial canal
  Jellyfish 167
  Sea urchin 175
  Starfish 174
Radial cartilage 180
Radial diffuser 418
Radial engine
  Curtiss biplane 398-399
  Lockheed Electra airliner 406-407
Radial groove 365
Radial nerve
  Human 238
  Sea urchin 175
Radial river drainage 288
Radial spoke 47
Radial studio easel 437
Radial wall 465
Radiation 38
  Electromagnetic 314
  Energy emission from Sun 22
  Galaxies 12-13
  Nebulae and star clusters 16
  Ozone formation 64
  Universe 10
Radiative zone
  Structure of main sequence star 24
  Structure of Sun 33
Radiator
  1906 Renault 336-337
  ARV light aircraft 424
  Ford Model T 338-339
  Hawker Tempest fighter 409
  Honda VF750 364
  Kirby BSA 369
  Renault Clio 351
  Wright Flyer 399
Radiator-access cowling 408
Radiator air vent 368
Radiator apron 339
Radiator coolant 326
Radiator fan 326
Radiator filler neck 339
Radiator header tank 408
Radiator hose 339
Radiator outlet 409
Radiator pipe 364
Radiator shell 339
Radicle
  Dry fruit 150
  Embryo development 147
  Epigeal germination 153
  Hypogeal germination 152
Radio
  Bell-47 helicopter 422
  Renault Clio 353
  Streamed internet 577
Radio aerial 426
Radio antenna 395
Radio galaxies 12-13
Radio image 13
Radio-isotope thermo-electric generator 614
Radio lobe 13
Radio mast 494
Radio operator's seat 408
Radio plugs 425
Radio speaker 353
Radio tuner aerial socket (FM) 585
Radio tuner FM/AM selector 585
Radio-ulna 183
Radio wave beam 28
Radio-wave emission 15
Radio waves
  Electromagnetic spectrum 318
  Pulsar 28
  Radio image of Centaurus A 13
Radium 310
Radius
  Archaeopteryx 85
  Arsinoitherium 104
  Baryonyx 85
  Bird 189, 191
  Circle 622
  Crocodile 186
  Diplodocus 90
  Domestic cat 195
  Elephant 90, 201
  Eryops 80
  Euoplocephalus 94
  Hare 197
  Horse 199
  Human 218, 230-231
  Iguanodon 96
  Kangaroo 206
  Lizard 184
  Parasaurolophus 99
  Pareiasaur 81
  Plateosaurus 88
  Platypus 206
  Rhesus monkey 202
  Seal 204
  Stegoceras 100-101
  Struthiomimus 87
  Toxodon 106
  Triceratops 102
  Turtle 187
Radius arm 357
Radius rod
  Avro Tutor biplane 403
  Ford Model T 338-339
Radome
  BAe-146 jetliner 415
  Concorde, the 416-417
  Tornado 420
Radon 311
Radula 176-177
RAF Central Flying School badge 402
RAF roundels 403, 409
Raft 496
Rafter
  Ancient Roman mill 464
  Dome 486
  Gothic building 473
  Modern building 499
  Nineteenth-century building 492
Raft spider 171
Rail
  Electric tram 332
  Kayak 560
  Neoclassical building 483
  Relief-printing press 449
  Train 330-331
  Wooden sailing ship 379
Rail chair 324
Railing
  Asian building 490-491
  Cathedral dome 487
  Medieval building 467
  Nineteenth-century building 493
  Renaissance theater 477
Railroad crest 326
Railroad system 324
Rain 302
Rain erosion 294
Rain gutter 412, 415
Rainwater
  Caves 284
  Weathering and erosion 282
Raised beach 295
Raja clavata 179
Raked windshield 333
Raking cornice
  Ancient Greek building 460-461
  Ancient Roman building 462-463
  Baroque church 480-481
  Neoclassical building 478
Raking stempost 376
Ram 372
Ramaria formosa 114
Ramentum 112, 121
Rammer 396
Ramp 467, 494
Ram scoop
  BE 2B bomber 404
  Tornado 420-421
Rangefinder
  Battleship 394
  Gun turret 396
Ranks 514
Ranunculus sp. 127, 132-133
Raphe 153
Rapid-fire pistols 548
Rapids
  River features 290
  River's stages 289
Rare earths 310
Rare gases 311
Ras Algethi 20
Ras Alhague 19, 20
Rasp 452
Raspberry 149
Rat 104, 196
Ratchet
  Brace-and-bit 601
  Fixed-spool reel 562
Ratcheted base 590
Ratchet mechanism 601
Ratchet wheel 334
Rating 378
Ratings' mess 397
Ratline 376, 379
Rat's tail 384
Rat tail 389
Rattlesnake 185
Raw sienna 434
Raw umber 434
Ray
  Branchiostegal 181
  Caudal fin 180
  Dorsal fin 181
  Jawless fish 178
  Liverwort 118
  Mercury 34
  Near side of the Moon 40
  Parenchyma cells 134
  Pectoral fin 181
Ray crater 34
Ray florets
  Florists' chrysanthemum 129
  Sunflower 142, 145
Reactants 312
Reaction wheel 614
Reactive metals 310-311
Reactor core 314
Reactor space 397
Rear axle 338
Rear axle adjustor 364, 368
Rear bearing 411
Rear brake 362
Rear brake cable 359, 360
Rear brake calliper 368
Rear brake pedal 368
Rear bulkhead 417
Rear cantilever brake 358
Rear case 591
Rear chassis plate 597
Rear cylinder exhaust pipe 368
Rear derailleur 358, 360
Rear door 339
Rear dropouts 358
Rear hatch 349
Rear hub quick-release spindle 358
Rear indicator 362
Rear lamp
  Oldsmobile trim 337
  Volkswagen Beetle 340
Rear leaf spring 338
Rear light
  Bicycle 360
  Italian State Railroads Class 402 328
  Paris Metro 328
Rear limit line 557
Rear-mounted propeller
  Pegasus Quasar ultralight 426
  Pioneers of flight 398-399
Rear oil lamp 336

Rear shelf 352
Rear shock absorber 340
Rear subframe 364
Rear tail light 329
Rearview mirror
1906 Renault 336
Formula One race car 357
Renault Clio 353
Receiver
American squash 545
Badminton 545
International squash 545
Racketball 545
Tennis 544
Receiving line 545
Receptacles
Algae 116
Dicotyledon flower 127
Dry fruit 150-151
Fertilization 147
Flower 140-36
Rose 131
Seaweed 116-117
Succulent fruit 148-149
Recessed arch 488
Recessed hinge 414, 415
Rechargeable battery
Digital camera 581
Nintendo Wii Fit Plus 579
Recharge area 292
Reclining seat 572
Recoil cylinder 396
Reconnaissance camera 420
Recorded information 521
Recording light 583
Record/Stop button 586
Rectal cecum 174
Rectal gland 179
Rectangle 622
Rectangular block 623
Rectangular cross-band 374
Rectangular pier 465, 467, 480
Rectangular river drainage 288
Rectangular window
Ancient Roman building 465
Asian building 490
Baroque church 481
Medieval building 466
Renaissance building 474, 476
Rectum
Bird 189
Butterfly 169
Chimpanzee 202
Cow 198
Dogfish 179
Dolphin 205
Elephant 200
Frog 182
Human 215, 248-249, 258-259, 261
Lizard 185
Rabbit 196
Starfish 174
Tortoise 187
Rectus abdominis muscle 226
Rectus femoris muscle 226
Recumbent fold 61
Red algae 116
Red blood cells 217, 253
Red-brown crocoite 271
Red card 524
Red cedar boarding 602
Red cell 584
Red deer 199
Red dwarf 23
Red earth 433, 434-435
Red filter signal light 407
Red giant
Small stars 24-25
Stars 22-23
Red howler monkey 203
Red light 318
Main-line signaling system 330, 331
Red light photon 318
Red marble 450
Red port navigation light 406
Red sandstone 277
Red seaweeds 117
Red spot 44-45
Red supergiant
Massive stars 26-27
Stars 22-23
Reduction gearbox
Early piston aero-engines 410-411
Jet engines 419
Turboprop engine 419
Redwall limestone 277
Red warning light
Italian State Railroads Class 402 328
Paris Metro 328
Redwood trees 70
Reed pen 444
Reef knot 388
Reef point 385
Reel
Angling equipment 562-563
Fencing piste 557
Frigate 397
Reel foot 562-563
Reel scoop 562-563
Reel seat 563
Reentrant angle 485
Reentrant corner 479
Referee
Basketball 532
Football 526
Gaelic football 529
Ice hockey 550
Judo 556
Lacrosse 541
Rugby 530
Soccer 524
Swimming 558
Volleyball 534
Referee's crease 550
Refe'ree's equipment 524
Referee's signals
Basketball 533
Football 527
Reflection 318
Reflection nebula 16
Reflector
Ford Model T 339
Oldsmobile trim 337
Refraction 318-319
Refractory (heat-resistant) skin 421
Refrigerator freight car 327
Régie Autonome des Transports Parisien 328
Regional metamorphism 274
Regional weather 302
Registers 514
Regolith (soil) 41
Regula 461
Regulator
"Mallard" express steam locomotive 325
"Rocket" steam locomotive 324
Regulator valve 325
Regulus 18, 21
Rein 554
Reinforce 395
Reinforced concrete 494, 497
Ties 330
Reinforced plinth 499
Rein terret 555
Relative atomic mass 310
Relay baton 543
Relay running 542
Release 537, 543
Release adjustment screw 552
Release button 425
Release catch 590
Release lever 563
Release spring 563
Relief 458
Relief printing 446
Relief printing equipment 449
Relieving arch
Ancient Roman building 462, 465
Medieval building 466-467
Remiges 188, 191
Remote control 584, 585
Remote control sensor 585
Remote sensing palette 614
Removable archery screen 377
Renaissance buildings 474-477
Renal artery 256-257
Renal column 256
Renal papilla 256
Renal pelvis 256
Renal sinus 256
Renal vein 256-257
Renault (1906) 336-337
Renault Clio 348-353
Renault logo 348
Renewable energy 604-605
Renoir 35
Repeater indicator 333
Repeating pattern 307
Replum 151
Reply all button 576
Reply button 576
Reproduction
Algae 116-117
Cloning 606-607
Fertilization 146-147
Flowering plants 140
Liverwort 118
Moss 118-119
Vegetative 154-155
Reproductive canal 94
Reproductive chamber 116
Reproductive organs 259
Reproductive structures
Flower 140-143
Pollination 144
Reproductive system 258-259
Reptiles 80-81, 184-187
Carboniferous period 66
Dinosaurs 82-83
Fossil record 279
Jurassic period 70
Present-day 82
Rhynchosaurian 71
Synapsid skull 67
Triassic period 68
Reptilia 184, 186
Repulsion 316-317
"Request identification" aerial 421
Reradiated heat 300-301
Reredos 470
Rescue strap 561
Reservoir 314
Reset button 560
Resin canal
Bishop pine needle 124
Pine root/stem 125
Resistance 316
Resonator 513
Respiration 255
Respiratory system 254-255
Rest
Musical notation 502
Newton's first motion law 321
Resurgence 284-285
Retaining bolt hole 366
Retaining screw 562, 563
Reticulum
Digestive system of a cow 198
Southern stars 20
Retina 240-241
Retraction jack 417
Retractor muscle 167
Retreating glacier 286
Retrices 188
Retroarticular process 83
Return 486-487
Rev counter 369
Reversed bend hook 562
Reversed dive piked 559
Reverse dip-slip fault 61
Reverse dive 558
Reverse-flow combustion chamber 418
Reverse lever 342
Reverser handle 325
Reverse shock wave 27
Reversible reactions 312
Reversing shaft lock control 325
Reversing wheel 392
Revivalist style 493-494
Rewind button 577
Rhamphodopsis 65
Rhamphorhynchus sp. 71
Rheas 188
Rhenium 310
Rhesus monkey 202
Rhinoceroses 198-199
Rhizine 114
Rhizoids 118-119
Alga 116
Fern 121
Liverwort 118
Moss 119
Rhizomes 154-155
Fern 121
Herbaceous flowering plants 128
Horsetail 120
Water hyacinth 158
Water lily 159
Rhizophore 120
Rho1 Sagittarii 21
Rhodium 311
Rhodophyta 116
Rhomboideus major muscle 227
Rhomboid leaves 137
Rhombus 622
Rhopalium 167
Rhynchosaurian reptile 71
Rhynchosaurs 68-69, 71
Rhyolite 274-275
Rhyolitic lava 272
Rhythm
Drums 518
Percussion instruments 516
Rhythm pattern selector 520
Rib
Acoustic guitar 512
Archaeopteryx 85
Avro triplane 403
Baroque church 479
BE 2B tail 405
BE 2B wings 404
Bird 189
Blackburn monoplane 401
Bony fish 181
Brachiosaurus 90
Concorde, the 417
Crocodile 186
Diplodocus 90
Dome 486-487
Domestic cat 195
Double bass 511
Elephant 201
Eryops 80
Euoplocephalus 94
Gallimimus 86
Hare 197
Herbaceous (lowering plant 128
Horse 199
Kangaroo 206
Lizard 184
Medieval church 469
Modern building 499
Pareiasaur 81
Pegasus Quasar ultralight 426-427
Pegasus XL SE ultralight 426
Plateosaurus 88
Platypus 206
Rhesus monkey 202
Seal 204
Snake 185
Stegoceras 101
Struthiomimus 87
Toxodon 107
Triceratops 102
Tyrannosaurus 84
Violin 510
Westlothiana 81
Riband 381
Ribbon connectors 585
Ribbon Lake 287
Ribbon window 499
Rib cage
Carnivores 195
Human 218
Ribosome
Chloroplast 139
Human cell 217
Rib vault 469, 484-485
Gothic building 470
Medieval building 467
Renaissance building 477
Rice paper 445
Ride cymbal 519
Ridge
Epigeal germination 153
False septum 151
Gothic building 473
Modern building 499
Nineteenth-century building 492
Seed 153
Twentieth-century building 495
Ridge and furrow roof 492
Ridge-board 473
Ridge-rib 469, 485
Ridges 286-287
Ridge tile 464, 476
Riding bitt 372
Riding jacket 554
Riffler 452, 453, 454
Rifle 548, 549
Rift valley 58
Lake formation 292-293
Rig 384-385
Riga brush 434
Rigel
Northern stars 18
Orion 18
Southern stars 21
Star magnitudes 22
Rigger 560
Rigger's gauge 382
Rigging 382-383
Iron 392
Sailing dinghy 561
Wooden sailing ship 378-379
Rigging rail 376
Rigging tools 382-383
Right-angled triangle 622
Right cylinder 623
Right edge guide 575
Right whales 204
Rigid rock 60
Rigol 381
Rim
Bicycle wheel 358-359
Kayak paddle 560
Paddle wheel 391
Tam-tam 516
Twin bollards 386
Rim brake 330
Rim clamp 357
Rim of pitcher 161
Rim plate 390
Rim section 390
Rind 149
Ring
74-gun ship 380
Mushroom 115
Roman corbita 372
Ring 1986 U1R 48
Ring 1986 U2R 48
Ring 6 48
Ring bolt 373
Ring canal
Sea urchin 175
Starfish 174
Ring dyke 26
Ring finger 230-231
"Ring of Fire" 272
Ring of trunk 201
Rings
Jupiter 44-45
Neptune 50-51
Saturn 46-47
Uranus 48-49
Rings 4 and 5 48
Ring scar 130, 131
Ring-tailed lemur 203
Rink corner 550
Riojasaurus 89
Ripple finish 451
Riser
Bronze casting 454, 455
Staircase 477
Rising air
Atmospheric circulation and winds 300
Precipitation 302
Rising land 294
Risorius muscle 229
Rissa tridactyla 190
Ritchey 43
River Amur 265
River banks 289, 290
Riverbed 289
River capture 288
River cliff 289, 290
River course 288
River development 289
River drainage patterns 288
River features 290-291
River flow 290
River mouth 290
Rivers 288-289
Earth's physical features 264
River features 290-291
Rock cycle 266-267
Weathering and erosion 282
River source
River features 290
Rivers 288
River's stages 288-289
River terrace 290-291
River valley 288, 289, 290
Rivetted plates 392
Road spring 340
Roband 372, 374
Robie House 495
Robinia pseudoacacia 136
Roboreptile 609
Robots 608-609
Robot dogs 609
Roche 41
Roches moutonnées 286
Rock compression 60
Rock crystal 271
Rock cycle 266-267
Rock debris 295

Rock deformations 60, 61
Rocker 446
Rocker arm 366
Rocker-beam 496-497
Rocker cover 347, 354
Rocker deployment actuator 615
Rock erosion 282
Rocker keypad 591
Rocker pad 590
"Rocket" steam locomotive 324
Rocket launcher 397
Rock fracture 60
Rock ground mass 269
Rocking beam 334
Rocking elevator arm 424
Rocking lever 342
Rock layer
  Caves 284
  Faults and folds 60
Rock lip
  Cirque formation 287
  Tarn lake 293
Rock mounds 286
Rock particles 266-267
Rock pavement 282-283
Rock pedestal 282-283
Rock prisms 61
Rocks
  Faults and folds 60-61
  Fossils 278-279
  Igneous and metamorphic rocks 274-275
  Mineral resources 280
  Minerals 268
  Rock cycle 266-267
  Sedimentary rocks 276
  Weathering and erosion 282
Rock salt
  Halides 269
  Sedimentary rocks 276-277
Rock scar 284
Rock stonecrop 128
Rock strata 60, 61
  Fossils 278
Rock stress 60, 61
Rock tension 60, 61
Rocky Mountains 73, 75, 77, 264
Rocky planets
  Mars 42-43
  Mercury 34-35
  Solar system 30-31
  Venus 36-37
Rococo style 478
Rod 562-563
Rodentia 104, 196
Rodents 196-197
Rod-shaped structure 144
Rogers, R. 496
Roll 400
Roller
  Mid West single-rotor engine 410
  Motorized brushbar floor tool 593
  "O Ring" drive chain 366
  Painting tool 442
  Printing equipment 447, 449
  Tenor saxophone 509
Roller-bearing axle box 327
Roller-blind 497
Roller path 396
Rollers 596
Rolling hitch 388
Rollover button 577
Roll paper holder 575
Roll paper holder adapter 575
Roll paper manipulation button 574
Roll spoiler 414
Roll-spoiler hydraulic actuator attachment 414
Rolls-Royce Olympus Mark 610 turbojet 417
Roman anchor 372
Roman architecture 462-465
Roman corbita 372-373
Romanesque style 468, 470
Roman mill 464
Roman number system 591
Roman ships 372-373
Roof boss 468
Roof construction 603
Roof dome 332, 333
Roofed space 479
Roofing tile 482
Roofless temple 460
Roof molding 352
Roofs 484
  Ancient Egyptian temple 458-459
  Ancient Roman building 462
  Asian building 490
  Baroque church 481
  Dome 486
  Gothic building 470-473
  Hammer-beam 470, 473
  Islamic building 488-489
  Medieval building 467, 468
  Modern building 496-499
  Neoclassical building 479, 483
  Nineteenth-century building 492
  Renaissance building 476-477
  Twentieth-century building 494-495
Root
  BAe-146 jetliner components 413, 415
  BE 2B wings 404
  Tooth 247
Root canal 247
Root cap
  Broad bean 133
  Radicle 153
Root growth 282
Root hairs 132
Root nodule 128
Root of tail 198
Root parasite 163
Root-proof membrane 603
Root rib 413
Roots 132-133
  Adventitious 112-113
  Amaryllis 155
  Begonia 155
  Brassavola nodosa 162
  Broomrape host 163
  Carrot 128
  Cell division 133
  Clubmoss 120
  Couch grass 113
  Dehiscent fruit 150
  Dicotyledons 127
  Elongation region 133
  Embryo 147
  Epigeal germination 153
  Epiphytes 162-163
  Fern 121
  Germination 152-153
  Ginger 155
  Gladiolus 155
  Golden barrel cactus 156
  Grape hyacinth 155
  Horse chestnut 130
  Horsetail 120
  Hypogeal germination 152
  Ivy 131
  Kedrostis africana 113
  Lily 155
  Monocotyledons 126-127
  Mycorrhizal association 133
  Oxalis sp. 157
  Pine seedling 122
  Potato 128
  Rock stonecrop 128
  Seedling 152-153
  String of hearts 157
  Sweet pea 128
  Sweet potato 155
  Vegetative reproduction 154-155
  Water hyacinth 158
  Water transport 138
Root scar 128
Root succulents 157
Root tip 132-133
  Radicle 152-153
Root tubers 154-155, 157
Rope and paterae decoration 459
Rope band 372
Rope hole 386
Rope molding 395
Rope parrel 373
Rope preventer 378
Ropes 388-389
Rope serving mallet 383
Rope strand 384
Rope woolding 379
Rope work 388
Rorquals 204
Rosa sp. 130-131, 135
Rose 130-131
Rose quartz 271
Rosette
  Epiphytic plants 162-163
  Neoclassical building 480
Rosette Nebula 11
Rossby waves 300
Rossin Italian time-trial bicycle 361
Rostellum 16
Rostral bone 102, 103
Rostrum
  Crayfish 173
  Dolphin 204
Rotary engine 346-347
  Blackburn monoplane 400
  Modern piston aero-engines 410-411
Rotary valves 507
Rotating beacon 407
Rotating drum 595
Rotating joint 612
Rotational period 36
Rotor
  Mid West rotary engine 411
  Rotor and seals 347
Rotor blade 423
Rotor chamber
  Mid West single-rotor engine 410
  Wankel rotary engine 346
Rotor gear 346-347
Rotor gear teeth 411
Rotor house 314
Rotor hub
  Bell-47 helicopter 422
  Schweizer helicopter 423
Rotor journal 347
Rotor lock 604
Rotor mast 422-423
Rotunda 462-463, 482
Rough 546
Rough endoplasmic reticulum 217
Rough terrain motorcycle racing 368
Rough-textured paper 439, 441
Roulette 446
Rounce 449
Round arch
  Ancient Roman building 464-465
  Baroque church 479-480
  Dome 484, 486-487
  French temple 485
  Gothic church 473
  Medieval building 467-469
  Nineteenth-century building 495
  Renaissance building 474-475
Round-arched window
  Ancient Roman building 465
  Baroque church 481
  Dome 486
  Medieval building 466, 468-469
  Neoclassical building 478
Round ball 524
Round-corner single limousine coachwork 336
Roundel
  Avro biplane 403
  Hawker Tempest fighter 409
Roundhead nib 444
Roundhouse 380
Round pin 335
Round shot 378
Round thimble 384
Route information 332
Route key 590
Rover 528
Rover equipment deck 615
Rowan 130-131
Rowing 560-561
Rowing boat 375
Rowing positions on a Greek trireme 373
RSS (really simple syndication) feeds 577
Rubber bungee shock absorber 425
Rubber cord suspension 402-403
Rubber guide wheel 328
Rubber mounting bush 365
Rubber puck 550-551
Rubber roller 449
Rubber sealing strip 413
Rubber-sprung wheel 400-401
Rubber tire 402
Rubber-tired running wheel 328
Rubber wheel-guard 328
Rubber wheels
  Paris Metro 328
  "People Mover" 328
Rubbing
  Charcoal drawing 431
  Relief printing 446
Rubbing ink 448
Rubbing strake
  Mazda RX-7 346
  Roman corbita 372
Rubbing strip 353
Rubens 35
Rubidium 510
Rubus fruticosus 130, 146-147
Rubus idaeus 149
Ruckman 528
Rucknover 528
Ruckstell axle 339
Rudder
  ARV light aircraft 424
  Avro biplane 402
  Avro triplane 403
  BAe-146 jetliner 415
  Battleship 395
  BE 2B bomber 405
  Blackburn monoplane 401
  Blériot XI 401
  Concorde 416-417
  Curtiss biplane 399
  Dhow 376
  Frigate 396
  Greek and Roman ships 372-373
  Iron paddlesteamer 392
  Junk 376
  Lockheed Electra airliner 407
  Longboat 380
  LVG CVI fighter 405
  Northrop B-2 bomber 421
  Sailing dinghy 561
  Sailing warship 377
  Schleicher glider 426
  Submarine 396
  Tornado 421
  Viking boats 374-375
  Wooden sailing ship 378
  World War II aircraft 408-409
  Wright Flyer 399
Rudder cable
  ARV light aircraft 424
  Avro biplane 402
Rudder chain 378
Rudder head 376
Rudder hinge
  Avro biplane 402
  Blériot XI monoplane 401
Rudder mass balance 424
Rudder pedal 425, 573
Rudder post
  BE 2B bomber 405
  Blackburn monoplane 401
  Iron paddlesteamer 392
Rudder power control unit 417
Rudder strut 399
Rudder tip fairing 424
Rudder trimtab 409
Ruden 372
Rudimentary ear 260
Rudimentary eye 260
Rudimentary liver 260
Rudimentary mouth 260
Rudimentary vertebra 260
Ruellia grandiflora 145
Ruffini corpuscle 235, 239
Ruga 248
Rugby 524, 530-531
Rugby League 530-531
Rugby Union 530
Rules of algebra 621
Rumen 198
Ruminants 198
Rumpler monoplane 400
Run 536
Runners
  Bronze casting 454-455
  Rock stonecrop 128
  Strawberry 128
  Vegetative reproduction 154
Running 542
Running back 526
Running block 383
Running board
  Ford Model T 339
  1906 Renault 337
  Volkswagen Beetle 341
Running martingale 554
Running part 382
Running rail 328
Running rigging 382-383, 385
Running shoe 543
Running track 542
Running wheel 328
Runs 538
Rupes 34
Rupes Altai 40
Rush 135
Russian vine 131
Rustication
  Neoclassical building 479, 482-483
  Renaissance building 474-475
Rusts 114
Ruthenium 311

S

62 Sagittarii 21
Sabik 20
Sable brush
  Acrylics 442
  Calligraphy 444
  Oil paints 436
  Tempera 432
  Watercolors 438
Sabers 556-557
Saberur 557
Saber warning line 557
Sacajawea 37
Saccule 243
Sacral foramen 223
Sacral nerves 238
Sacral plexus 238
Sacral promontory 223
Sacral vertebra 183
Sacral vertebrae
  Diplodocus 90
  Eryops 81
  Human 223
  Iguanodon 96
  Parasaurolophus 98
  Plateosaurus 88
  Stegoceras 101
Sacristy 470
Sacrum
  Crocodile 186
  Domestic cat 195
  Elephant 201
  Hare 197
  Horse 199
  Human 218, 223, 259
  Kangaroo 206
  Lizard 184
  Rhesus monkey 202
  Seal 204
Saddle
  Acoustic guitar 512
  Bicycle 358-359
  Cannondale SH600 hybrid bicycle 361
  Eddy Merckx racing bicycle 360
  Horse racing 555
  Show jumping 554
  Werner motorcycle 362
Saddle clamp 360
Safety area 556
Safety barrier 552
Safety belt 356
Safety binding 552
Safety harness 357
Safety valve
  Bordino steam carriage 334
  Steamboat 391
Safe working load mark 383
Sagartia elegans 166
Sagitta 20
Sagittal crest 107, 194
Sagittal section through brain 236
Sagittarius 19-21

Sagittarius Arm 14
Sago palm 123
Sahara 39, 264-265
Sail
  Roman corbita 372-373
  Square-rigged ship 375
  Types 384-385
  Viking karv 374
Sail batten 376
Sailcloths 384
Sail foot control line 375
Sail hook 384
Sailing 560-561
Sailing rigs 384-385
Sailing warship 376-377
Sailmaker's whipping 382
Sailmaking tools 384
Sail patterns 379, 384
Saiph 18
Salamanders 182
Salient 466
Salisbury Cathedral 470-471
Saliva 244
Salivary gland
  Butterfly 169
  Snail 177
Salmon 109, 180
Salmon angling 562
Salmon bend gouge 452
Salmson radial engine 398-399
Salt
  Dead Sea 293
  Seawater sail content 296
Saltasaurus 72, 91
Salt-dome trap 281
Salt formation 312
Salt groundmass 277
Salt lakes 292
Samaras
  Dry fruit 150
  Sycamore 131, 150
Samarium 311
Sambucus nigra 130-131, 143
Samotherium 74
Samsung Galaxy Tab 569
San Andreas fault 58, 62-63
Sand-bars 290
Sand box 326, 327
Sand dunes
  Rock cycle 267
  Weathering and erosion 282-283
Sand groundmass 277
Sanding pipe 329
Sand-pits 546
Sandstone
  Marble tomb of Itimad-Ud-Daula 489
  Sedimentary rocks 276
Sand wave 299
Sand wedge 547
Sandy deposits 298
Sandy spit 295
Sanguine crayon 430
Sankey diagram 314
Sappho Patera 37
Sapwood 125
Saratoga Race Course 553
Sarcolemma 24
Sarcomere 24
Sarcophilus harrisii 207
Sarcoplasmic reticulum 24
Sarcorhamphus papa 190
Sarracenia purpurea 113
Sartorius muscle 226
Satellite 264
Satellite cable 586
Satellite map 264-265
Satellite speaker 586
Saturated zone 292-293
Saturn 46-47, 614
  Solar system 31
Saucer dome 486-487
  Ancient Roman building 462
Saurischia 82-83, 84, 88
Sauropoda 83
Sauropodomorpha 83, 88
Sauropodomorphs 88-91
Sauropods 70, 88
Savannah 74
Save as draft button 576
Saxboard 561
Saxophone 504, 508-509
Scala 372-373
Scale (musical) 502
Scale leaf scar 124, 155
Scale leaves
  Bishop pine 124
  Bulb 155
  Corm 155
  Epiphytic orchid 162
  Hypogeal germination 152
  Pine 122, 125
  Plumule 152
  Rhizome 155
  Sago palm 123
  Stem bulbil 155
Scalene triangle 622
Scalenus medius muscle 229
Scale of degrees 377
Scales
  Asteroxylon 79
  Bishop pine 124
  Bony fish 180
  Bract 122
  Brassavola nodosa 162
  Caiman 186
  Cartilaginous fish 178
  Crocodilians 186
  Dicotyledons 127
  False fruit 148
  Fern fronds 121
  Insects 168
  Lepidoptera wings 168
  Lizard 184
  Mushroom 115
  Ovuliferous 122-124
  Pine cone 122
  Pine shoot apex 125
  Rattlesnake 185
  Sago palm 122
  Tree fern 112
  Yew 123
Scallop 176
  Fossil 278
Scalloped hammerhead shark 179
Scalp 234, 236-237
Scaly lichens 114
Scaly skin
  Anchisaurus 89
  Corythosaurus 98
  Dinosaurs 82
  Edmontonia 95
  Echthyostega 80
  Iguanodon 97
  Pachycephalosaurus 100
  Psittacosaurus 103
  Reptile 80
  Snake 184
  Stegosaurus 92
  Triceratops 102
  Tyrannosaurus 84
  Westlothiana 81
Scandinavia 64, 69
Scandium 310
Scan head 571
Scanner 570-571
Scanning coils 611
Scanning electron microscope (SEM) 610, 611
Scan to email button 570
Scan to web button 570
Scapania undulata 118
Scape 168
Scaphoid bone 230
Scaphoid fossa 242
Scaphonyx fischeri 69
Scapula
  Archaeopteryx 85
  Arsinoitherium 104
  Bird 189
  Bony fish 181
  Brachiosaurus 91
  Crocodile 186
  Diplodocus 90
  Domestic cat 195
  Elephant 201
  Eiryops 80
  Euoplocephalus 94
  Gallimimus 86
  Hare 197
  Horse 199
  Human 210, 218
  Iguanodon 96
  Kangaroo 206
  Lizard 184
  Parasaurolophus 99
  Pareiasaur 81
  Plateosaurus 88
  Platypus 206
  Rhesus monkey 202
  Seal 204
  Stegoceras 101
  Struthiomimus 87
  Toxodon 106
  Triceratops 102
  Tuojiangosaurus 93
  Turtle 187
  Tyrannosaurus 84
Scapular muscle 91
Scarlet star 162-163
Scarph 395
Scars
  Horse chestnut 130
  Leaf 128-30, 134
  Rowan twig 131
Scavenge oil line 419
Scelidosaurus 71
Scent 144
Scheat 19, 20
Schedar 19
Schickard 40
Schist 26
Schizoearpic dry fruits 150-151
Schleicher K23 glider 426
Schlumbergera truncata 129
Schooner 384-385
Schrodinger 41
Schubert 35
Schwann cell 228, 239
Schweizer 300c 423
Sciatic nerve 238
Scientific notation 621
Scintigram 214
Scissor brace 475
Sciuris carolinensis 197
Sclera 213, 240
Sclereid 159
Sclerenchyma
  Fern rachis 121
  Horsetail stem 120
  Marram grass 113
  Monocotyledon leaf 126
  Stems 134-135
Sclerenchyma fibers 135
Scleroderma citrinum 115
Sclerotic ring 90, 99
Scooter 50-51
Score 388
Scorecard 547
Scorer
  Basketball 532
  Fencing contest 557
  Judo contest 556
  Lacrosse 541
  Netball 535
  Volleyball 534
Scoria 273
Scoring
  Australian rules football 528
  Badminton 544
  Baseball 536
  Basketball 552
  Cricket 538
  Gaelic football 529
  Hockey 540
  Hurling 540-541
  Netball 534
  Rugby 530-531
  Tennis 544
  Volleyball 534
Scorper 449
Scorpion 170, 278
Scorpiones 170
Scorpius 19, 20
Scotia 463, 485
Scots pine 122
Scraper 46
Scraper ring 344
Scratchplate 513
Scree 282-283
Screen
  Computer 576, 577, 611
  French baroque building 482
  Hydroelectric power station 314
  Islamic building 488-489
  Screen printing 448
  Streamed internet video 577
  Twentieth-century building 494
Screen bulkhead 381
Screen lens 589
Screen printing 446, 448
Screw 320
  Acoustic guitar 513
  Double bass bow 511
  Power drill 600
  Toaster 598
  Violin bow 510
Screw coupling 525
Screw down greaser 556
Screw fitting 319
Screw hole 600
Screw joint 413
Screw link 386
Screw locking nut 563
Screw pressure adjustor 447
Scriber 446
Scroll
  Cello 511
  Double bass 511
  Viola 511
  Violin 510
Scrolled buttress 478
Scroll motif 470, 491
Scroll molding 466
Scroll ornament 476, 479, 485
Scroll-shaped corbel.482, 487
Scrollwork 472
Scrotum 211, 259
Scrum-half 530
Scrummages 530
Scull 561
Sculling 560
Scull oar 560
Sculpted wing-root fairing 573
Sculptor 19, 20
Sculptural decoration 467
Sculpture 452-455, 493, 495
Sculptured testa 151
Scumbling 440-441
Scupper 595
Scute 186
Scutellum 168
Scutum 19
Scutum plate 175
Scyphozoa 166
Sea
  Anticline trap 281
  Fossils 278
  Hurricane structure 303
  River features 290-291
Sea anemone 166-167
Sea angling 562
Seabed
  Fossils 278
  Ocean floor 298
  River features 290
  Rivers 288
Seabed profile 299
Sea buckthorn 136
Seacat missile launcher 397
Sea-cave 295
Sea-cliff 294-295
  River features 291
Sea creature remains 298
Sea cucumber 174
Sea daisies 174
Sea-dwelling organic structures 78
Seafloor spread 58
Seahorse 180
Sea level 66
Sea-level variations 294
Sea lilies 174
Sea lion 204
Seals 204-205
Seam
  Rivetted plates 392
  Sail 584
Seaming twine 384
Seamounts 298
Sea of Japan 265
Search field 576, 577
Searchlight 394-595
Seas 296-297
  Igneous and metamorphic rocks 275
  Rivers 288
  Satellite map 265
Seasons 72
Seat
  1906 Renault 337
  Driver's 325, 328
  Faering 375
  Fireman's 325
  First cars 334-335
  Ford Model T 339
  Greek trireme 373
  Harley-Davidson FLHS Electra Glide 363
  Honda CB750 565
  Honda VF750 564
  Husqvarna Motocross TC610 368
  Kayak 560
  Longboat 380
  Motorcycle 364
  Racing sulky 355
  Renault Clio 352-355
  Showjumping saddle 554
  Suzuki RGV500 368
  TGV electric high-speed train 329
  Vespa Grand Sport 160
  Mark 1 363
  Weslake Speedway motorcycle 369
Seat angle 360
Seat assembly 425, 553
Seat attachment rail 416
Seat back rest frame 337, 352-353
Seat beam 399
Seatbelt attachment point 573
Seat belt catch 352
Seat control panel 572
Seat cushion 407, 425
Sea temperature 303
Seat frame 353
Seating 465
Seat mount 340
Seat pan 409
Seat post 358, 360
Seat post quick-release boll 358
Seat spring 335
Seat squab 335, 337
Seat stay 358, 360
Seat support strut 398
Seat tube 358, 360, 361
Sea urchins 174-175
Seawater
  River features 290
  Salt content 296
Seaweeds 116-117
Seaworm 78
Sebaceous gland 234-235
Secondary baffle 612
Secondary bronchus 215
Secondary colors 439
Secondary conduit 272-273
  Rock cycle 266
Secondary crater 34
Secondary flight feathers 188, 191
Secondary follicle 258
Secondary mirror 612
Secondary mycelium 115
Secondary phloem 134-135
Secondary remiges 188, 191
Secondary rotor 317
Secondary suspension 327
Secondary thallus 114
Secondary vascular tissue 134
Secondary xylem 125, 134-135
Second-century building 462
Second electron shell 509
Second mast 376
Second-row forward 530
Second slip 538
Second toe 232
Second violins 503, 504-505
Second wheel set 529
Secretory gland 161
Secretory thyroid gland cells 217
Secretory vesicle 216
Secure anchor 386
Security light 605
Sediment
  Coastlines 294-295
  Fossils 278
  Glaciers 286-287
  Lakes 292
  Mineral resources 280
  Mountain building 62-65
  Ocean floor 298-299
  River features 290-291
  Rivers 288
  Rock cycle 266-267
Sedimentary rocks 276-277
  Igneous and metamorphic rocks 274
  Rock cycle 266-267
Sedna Planitia 36-37
Sedum rupestre 128
Sedum spectabile 128-129
Seed
  Apomixis 146
  Apple 149
  Cape gooseberry 149
  Dehydration 152
  Dispersal 148-151
  Dormancy 152
  Dry fruit 150-151
  Embryo development 147
  Fig 148
  Germination 132, 152-153
  Goosegrass 150
  Gymnosperms 122
  Hilum 148-149, 151-153
  Hogweed 151
  Honesty 151
  Larkspur 151
  Lemon 148

Love-in-a-mist 151
Lychee 148
Melon 149
Parts 152-153
Pea 150
Pine 122
Raspberry 149
Root development 132
Scots pine 122
Smooth cypress 123
Strawberry 150
Succulent fruit 148-149
Sweet chestnut 150
Sycamore 131, 151
Wind dispersal 150
Wings 150-151
Yew 123
Seed axis 152-153
Seed coat 132, 152-153
Dry fruit 150-151
Embryo development 147
Epigeal germination 153
Hypogeal germination 152
Succulent fruit 148-149
Seed fern 278
Seed leaves 126, 152-153
Dry fruit 150-151
Embryo development 147
Epigeal germination 153
Hypogeal germination 152
Pine 122
Succulent fruit 148-149
Seedlings
Epigeal germination 153
Hypogeal germination 152
Pine 122
Seed-producing organs 148-149
Seed scar 122
Seed stalks 150
Seed wings 151
Seek bar 577
Segmental arch 492
Segmental pediment 462, 478
Segnosauria 83
Seif dune 283
Seismic activity 58
Seizing 383, 384, 387, 388-389
Selaginella sp. 120
Select key 578
Selector fork 366
Selector switch 598-599
Selenite 270
Selenium 311
Self-pollination 144
SEM 601, 611
Semaphore signal 330
Semen 217
Semiarch 470-471
Semibreve 502-503
Semibulkhead 425
Semicircle 532
Semicircular canals 243
Semicircular tower 465
Semiconductor 306
Semidome 484, 482, 488
Semielliptical arch 484
Semielliptic leaf spring 342
Semilunar fold 249
Semi-metals 310-311
Seminal receptacle 169
Spider 170
Seminal vesicle 259
Semiquaver 502
Semisolid core 37
Semisolid outer core 41
Semisprawling stance 82
Westlothiana 81
Semitendinosus muscle 227
Send button 576
Sender's name 576
Senior ratings' mess 397
Sensory antenna 168
Sensory hinge 160
Sensory tentacle 176
Sent mail folder 576
Sepal 140-143
Clematis 131
Dicotyledons 126-127
Dry fruit 150-151
Everlasting pea 129
Fertilization 146-147
Monocotyledons 126
Peruvian lily 129
Pitcher plant 113
Pollination 145
Rose 131
Succulent fruit 149
Sepal remains 146-147
Sepal sheath 141
Separated carpels 151
Separator 576
Septime 557
Septum 115
False 151
Interventrieular 251
Nasal 213, 241
Placenta 260
Sequencer 521
Sequoiadendron sp. 70
Series electrical circuit 316
Serif 445
Serous pericardium 250
Serpens Caput 18, 21
Serpens Cauda 19, 20
Serpentes 184
Serpentine neck 374
Serrated tooth 84, 85, 88
Serrate leaf margins 129
Serratus anterior muscle 226
Server 534, 544 , 545, 576
Server Service 544
Service area 534
Service box line 545
Service court 544, 545
Service crane 605
Service door 415
Service judge 544, 545
Service line 544, 545
Service shaft 498
Service zone 545
Serving 388
Serving mallet 383, 384, 388
Servo control-unit fairing 417
Servo-tab 414, 415
Sesamoid bone 198
Seta 112, 119
Set-back buttress 481
Set square 445
Settings control panel 574
Settings display 574, 575
Setting select buttons 575
Seven Sisters 14
Seventeenth century 474
Building 479-481, 488
Capital 490
Dome 486-487
Roof 490
Style 478
Tomb 489
Seventh century
Building 491
Sevier fault 276
Sex cells 154
Fertilization 146-147
Gametophyte plants 120
Gymnosperms 122
Liverwort 118
Moss 118-119
Sextans 21
Sexual reproduction
Algae 116-117
Bryophytes 119
Flowering plants 140-147
Mosses 118-119
Seaweed 116-117
Spirogyra sp. 117
Seyfert 41
Seyfert galaxies 12-13
Shackle 382, 386
Shackle pin 382
Shaft
Ancient Egyptian column 459
Ancient Greek temple 461
Ancient Roman building 463, 465
Arrow 548
Asian building 490-491
Badminton racket 545
Electric generator 517
Feather 191
Femur 225
French temple 485
Golf club 547
Harness racer 555
Hydroelectric power station 314
Javelin 542
Kayak paddle 560
Medieval church 468-469
Modern building 498
Neoclassical building 478, 483
Nineteenth-century building 493
Phalanx 230
Power drill 600
Roman Corbita 373
Sculling oar 560
Ski pole 553
Squash racket 545
Shaft drive 366
Shale
Contact metamorphism 274
Grand Canyon 277
Shallow carvel-built hull 391
Shallow Hats 293
Shank
Anatomy of a hook 562
Danforth anchor 386
Hook 383
Roman anchor 372
Sail hook 384
Shackle pin 382
Shannon bone 198
Shape
Chemical reactants 312
Matter 306-307
Periodic table 310
Shapes (plane; solid) 622
Sharks 178-179, 180
Sharp 502
Sharpey's fiber 225
Shaula 19, 20
Shave 374
Shaving foam 306
Shearing 61
Sheave 383
Sheave for cat tackle 380
Sheep 198
Sheepskin numnah 554
Sheer 374
Sheerplank 380
Sheer pole 373
Sheer strake 375, 393
Sheet 372, 375, 382
Sheet anchor 395
Sheet bend 389
Sheet feeder 575
Sheet-iron louvre 493
Sheet lead 383
Shelf formation 282
Shell
379 cm shell 397
6 in shell 397
Building 464, 476
Chelonians 186
Crab 172
Dorsal margin 176
Egg 192-193
Exploding 394, 396-397
Fossil 278
Massive stars 26
Mollusk 176-177
Octopus 176
Rib 176
Rudiment 176
Scallop 176
Small stars 24-25
Snail 177
Standing block 382
Terrapin 187
Ventral margin 176
Shell bogie 396
Shell case 397
Shelled invertebrates 56
Shelley 35
Shell-like fracture 270
Shell room 396
Shelly limestone 267
"Shiaijo" 556
Shield 394-395
"Shield bearers" 92
Shielded receiver 591
Shield plate 570
Shield volcano 42
Shin
Herrerasaurus 86
Human 211
Shinarump member 276
Shin guard
Slalom skiing 553
Soccer 525
Shinty 540
Shinumo quartzite 277
Ship 387
74-gun ship 379, 380-381
Ship of the line 380-381
Ship's cannon 376, 394
Ships of Greece and Rome 372-373
Ship's shield 394-395
Ship's wheel 378, 390, 394
Shipwright 374
Shiv 383
Shiver 383
Shock absorber
1906 Renault 336
ARV light aircraft 425
Football helmet 527
Honda CB750 363
Honda VF750 364
Renault Clio 350
Suzuki RGV500 368
Vespa Grand Sport 160
Mark 1 363
Volkswagen Beetle 340
Shock-absorbing platform 553
Shock-absorbing spring 401, 405
Shock-strut 401
Shock waves 27
Path 63
Athletics 543
Basketball 533
Golf 547
Handball 535
Rowing 560
Shoes
Baseball 537
Football 527
Hurling 541
Riding 554
Rugby 531
Sailing 560
Ski 552
Soccer 525
Shoot
Broomrape 163
Embryo 147
Horsetail 120
Hypogeal germination 152
Pine 125
Vegetative reproduction 155
Shoot apex 125
Shooting 548-549
Shooting circle 540
Shooting positions 548
Shoreline
Coastlines 294
Continental-shelf floor 298
Short line 545
Shorts
Australian rules football 529
Hurling 541
Soccer 525
Volleyball 534
Short saphenous vein 253
Shortstop 536
Short-wave radio 318
Shot
Field events equipment 542
Gun 378
Shot garland 381
Shot put 543
Shot-put circle 542
Shot-put fan 542
Shoulder
Anchisaurus 89
Cello 511
Corythosaurus 98
Double bass 511
Gorilla 203
Harp 511
Horse 199
Human 210
Iguanodon 97
Rabbit 196
Rigging 382-383
Stegoceras 101
Stegosaurus 92
Viola 511
Violin 510
Shoulderblade 210, 218
Shoulder cowling 412
Shoulder girdle 80
Shoulder joint
Brachiosaurus 91
Gallimimus 86
Human 218
Parasaurolophus 99
Plateosaurus 88
Triceratops 102
Tyrannousaurus 84
Shoulder pad 426
Shoulder padding 551
Shoulder pass 535
Shoulder spikes
Edmontonia 95
Euoplocephalus 94
Shoulder wheel throw 556
Showjumping 554
Shreve, R.H. 494
Shrewlike mammals 70
Shrimp 172
Fossil 79
Shrine 490-491
Shroud
Dhow 376
Longboat 380
Rigging 383
Roman corbita 373
Sailing dinghy 561
Sailing warship 376
Shrubs 130-131
Shuffle button 586
Shutter button 581
Shutter for gun 394
Shuttlecock 544-545
Shuttle switch 586
Sickle motif 491
Sidalcea malviflora 136
Side aisle
Cathedral dome 484
Gothic church 472-473
Medieval church 469
Side bench 380
Side brace and retraction jack trunnions 414
Sidecar
BMW R/60 362
Motorcycle racing 368-369
Side chapel 469-470, 479
Side counter timber 381
Side-cowling 408
Side drum 504-505
Side fairing 415
Side forequarter hold 556
Side gear 347
Side housing 346-347
Side lamp 338-339
Sidelight 332, 333, 362
Sideline
Badminton 545
Basketball 532
Football 526
Handball 535
Hockey 540
Men's lacrosse 540
Netball 535
Tennis 541
Volleyball 534
Side marker lamp 346, 349
Side-mounted engine 398
Side plate 562
Side pod 356, 357
Side reflector 562, 363
Siderite band 277
Side rudder 374-375
Side-shooting 541
Side vent 329
Side wall 545, 558
Side-wall line 545
Sideways erosion
River features 290
Rivers 288
Sierra Madre 264
Sierra Nevada 57, 75
Sieve tubes 134
Sieving beak 188
Sif Mons 37
Sight 394
Sight pin 549
Sight screen 538
Sighting hood
Battleship 394
Gun turret 396
Sighting rule 376-377
Sights 548-549
Sigma Canis Majoris 21
Sigmoid colon 249
Signal flag compartment 397
Signal gear 395
Signaling systems 330-331
Sikorsky, Igor 422
Silence 502
Silencer
Harley-Davidson FLHS
Electra Glide 362
Renault Clio 350
Suzuki RGV500 368
Vespa Grand Sport 160
Mark 1 363
Weslake Speedway motorcycle 369
Silencing heat exchanger 404
Silicate core 51
Silicate dust 53
Silicate material 39
Silicate rock 39
Silicates 269
Siliceous ooze 299
Silicon 26
Earth's composition 39
Earth's crust 58
Periodic table 311
Variety of matter 306
Siliquas 150-151
Silk gland 170

Sill 26
Ancient Roman mill 464
Renaissance building 475
Twentieth-century building 494
Sill trim 353
Silly mid-off 538
Silly mid-on 538
Silurian period
Fossil record 279
Geological time 56
Silver
Mineral resources 280-281
Minerals 268
Periodic table 311-312
Streak 271
Silver lines 430-431
Silver molybdenite 271
Silver nitrate solution 312
Silverpoint 450, 431
Silver wire 430
Silvery metals 310
SIM (Subscriber Identity Module) card slot 589
Simple electrical circuit 316
Simple eye 170-171
Simple leaves 136-137
Entire 130
Hastate 128
Herbaceous flowering plants 128-129
Lanceolate 131
Lobed 131
Simple machines 320
Simple Machines Law 320
Simple succulent fruits 148-149
Single bass note siring 515
Single-celled micro-organisms 78
Single clump block 375
Single cylinder 335
Single-decker bus 352, 333
Single flowers 140-141, 143
Single front driving wheel 354
Single-glazed conservatory 602
Single-leg main landing gear 407
Single overhead cam engine 363
Single-piece skin 413
Single-pulley system 320
Single reed 508, 509
Singles 544
Single scull 560, 561
Single sheet bend 387
Single-sided trailing-link fork 363
Single wing hold 556
Singularity
Formation of black hole 29
Stellar black hole 29
Sinistral strike-slip fault 61
Sink-holes 284-285
Sinking land 294
Sinopia 434, 435
Sinous venosus sclerae 241
Sinuous cell wall 156
Sinus
Frontal, 212, 245
Green alga 112
Renal 256
Superior sagittal 212
Sinus Borealis 69
Sinus Irid um 40
Siphon
Octopus 176-177
Sea urchin 175
Siphonoglyph 167
Sirius
Canis Major 21
Northern stars 18
Our galaxy and nearby galaxies 15
Southern stars 21
Spectral absroplion lines 25
Star magnitudes 22
Sirius A 25
Sirius B 23
Site icon 577
Sixteenth century
Building 476-477
Staircase 472
Style 462, 470
Size (glue) 431, 432, 436
Skarn 26
Skate
Chondrichthyes 178
Ice hockey 550, 551
Skeletal muscle 228
Skeletal muscle fiber 228
Skeleton
Archaeopteryx 85
Arsinoitherium 104-105
Baryonyx hand 85
Bat 105
Bird 189
Bony fish 180-181
Cow's fool 198
Crocodile 186
Diplodocus 90
Domestic cal 195
Klephant 201
Eryops 80-81
Frog 185
Hare 197
Horse 199
Human 218-219
Iguanodon 96
Kangaroo 206
Kentrosaurus 93
Lizard 184
Parasurolophus 98-99
Pareiasaur 81
Plateosaurus 88-89
Platypus 206
Rhesus monkey 202
Seal 204
Snake 185
Spider 171
Sponge 166
Stegoceras 100-101
Stegosaurus 95
Struthiomimus 87
Toxodon 106
Triceralops 102-103
Tuofiaiigosaiirus 95
Turile 187
Tyrannosaurus 84-85
Westlothiana 81
Sketch book 450
Skid 402, 404
Skid beam 380
Ski goggles 552, 555
Skiing 552, 553
Skilled movements 257
Skin
Amphibian 80, 182
Drumhead 518
Lizard 184
Reptile 80
Snake 184
Succulent fruits 148-149
Waterproof 81
Skin and hair 234-235
"Skin-grip" pin 424-425
Skin lap-joint 413, 414, 415
Skin tones 441
Ski pole 552
Skirting board 602
Skis 552
Skull
Acanthostega 80
Alligator 186
Ankylosaurus 94
Australopithecus 108
Baryonyx 85
Bear 194
Bird 189
Camarasaurus 91
Chimpanzee 202
Crocodilians 186
Diplodocus 90
Domestic cat 195
Elephant 201
Euoplocephalus 94
Fetal 220
Gharial 186
Hadrosaurs 96
Hare 197
Heterodontosaurus 85
Homo erect us 108
Homo habilis 108
Horse 199
Human 108, 212, 218, 220-221, 222, 236-257
Hyaenodon 107
Iguanodon 96
Kangaroo 206
Lambeosaurus 99
Lion 194
Lizard 184
Marginocephalian 100
Moeritherium 105
Octopus 176
Opossum 106
Pachycephalosaurs 100
Pachycephdlosaurus 100
Phiomia 105
Plateosaurus 88
Platypus 206
Prenocephale 100
Protoceratops 102
Rattlesnake 185
Rhesus monkey 202
Seal 204
Smilodon 107
Stegoceras 100
Styracosaurus 102
Synapsid reptile 67
Tortoise 77
Turtle 187
Skull bones 81
Skullcap 555
Skunks 194
Skylight
Battleship 394
Building 495, 494
Iron paddlesteamer 392-393
Skyscraper 494
Slab
Ancient Egyptian building 458-459
Modern building 499
Twentieth-century building 494
Slaked lime 434
Slalom
Skiing 552
Canoeing 560
Slalom clothing 553
Slalom equipment 553
Slalom gate 552
Slat 421
Slate 274, 275
Sleep button 585
Sleeper 324, 331
Sleeve port 343
Sleeve valve 543
Slender thistle 129
Slick racing tire 365
Kirby BSA 369
Suzuki RCV500 369
Slide 396
Slide bar 525
Slide brace 507
Slide locking lever 396
Slide track 561
Slide valve 590
Sliding bed 447
Sliding curtain 329
Sliding seat 561
Sliding window 333
Sling fixing point 349
Slip face 285
Slip faults 61
Slipher 43
Slope structure 60
Sloping roof 486
Slug 176
Slumped cliff 295
Slur 503
Smallbore rifle shooting 548
Smallbore rifle target 549
Small intestine
Brachiosaurus 90
Chimpanzee 202
Cow 198
Domestic cat 195
Elephant 200
Euoplocephalus 94
Frog 182
Human 214, 249
Lizard 185
Tortoise 187
Small Magellanic Cloud
Hydrus and Mensa 20
Our galaxy and nearby galaxies 15
Stars of southern skies 20
Small stars 24-25
Small theropods 87
Small-scale rock deformities 61
Smalti 450
Smalti mosaic 450
Smartphones 588-589
Smash 534
Smell 244
Smilodon 107
Smokebox 324, 325
Smoky quartz 268
Smooth cypress 125
Smooth endoplasmic reticulum 216
Smudging 430, 431
Smuts 114
Snail 176-177
Snake-head ornament 375
Snakes 184-185
Snap head 392
Snare 518
Snare drum 518
Snort mast 597
Snout
Anchisaurus 89
Caiman 186
Croeodilians 186
Dogfish 178
Edmontonia 95
Herrerasaurus 86
Iguanodonts 96
Jawless fish fossil 78
Pachycephalosaurus 100
Rat 196
Snow
Glaciers 286-287
Weather 302
Snowflake moray eel 180
Snowflakes 302
Soane, J. 478, 482-483
Sobkou Planitia 35
Soccer 524-525
Soccer uniform 525
Socle
Ancient Egyptian temple 458
Baroque church 479
Cathedral dome 487
Gothic church 472
Medieval church 469
Neoclassical building 478-479
Renaissance building 474
Soda lite 269
Sodium 35, 58
Periodic table 310
Seawater salt content 296
Sodium hydroxide 312
Sodium lines 23
Soffit 464, 484, 498
Soft eye 382
Soft hair brush 436, 338, 440
Soft-headed beater 516, 517, 519
Soft metals 310
Soft palate 212, 245
Soft pastels 440
Soft pedal 514, 515
Soft rock
River features 290
Weathering and erosion 282
Software effect plug-in 521
Solanum tuberosum 128
Solar array 612, 613, 615
Solar array supporting arm 613
Solar cell 603
Solar collector 605
Solar day 34
Solar eclipse 32
Solar flare 32-33
Solar panel 496, 605
Solar power 605
Solar radiation 300-301
Solar system 38, 30-31, 614-615
Solar wind
Earth's magnetosphere 58
Structure of comet 53
Sun 32
Solarium 494
Solar Wings Pegasus Quasar ultralight 427
Sole of foot 234
Soleplate 593
Soleplate roller 593
Soleplate surround 594
Soleus muscle 227, 233
Solfataras 272-273
Solid body 512, 513
Solid crystals 306
Solid heart thimble 385
Solidified lava
Lake formation 292
Volcanoes 272-273
Solid ink stick 444
Solid rubber tire 335
Solids 306-307
Chemical reactions 312
Solid shapes 622
Solutions 306, 312-313
Sonic sensor 609
Sombrero 12
Somites 79
SONAR bulge 397
SONAR torpedo decoy 396
SONAR transducer array 597
Sonic boom 416
Sonoran Desert 264
Sony B-series MP3 player 586
Sony DAV-S300 585
Sony W-series walkman 586
Soot particles 313
Sophocles 35
Soralium 114
Sorbus aucuparid 130-131
Soredia 114
Sori 120-121
Sostenuto pedal 514, 515
Sound 314-315
Coastline 295
Musical notation 502
Soundboard
Acoustic guitar 513
Concert grand piano 515
Harp 511
Upright piano 514
Viola 511
Violin 510
Sound channels 584
Sound hole
Acoustic guitar 512-513
Cello 511
Double bass 511
Viola 511
Violin 510
Sound module 521
South Africa 64
South America 264
Cretaceous period 72-75
Jurassic period 70
Late Carboniferous period 66
Middle Ordivician period 64
Quaternary period 76-77
Tertiary period 74-75
Triassie period 68
South American plate 59
South Asian buildings 490-491
South Atlantic Gyre 296
Satellite map 265
South Atlantic Ocean 39, 73
Southeast trade winds 300
Southeasterly wind 303
South Equatorial Belt 45
South equatorial current 296-297
Southerly wind 303
Southern Hemisphere 296-297
Southern polar region 64
South Galactic Pole 15
South Indian Gyre 297
South magnetic polar region 28
South Pacific Gyre 296
South Pacific Ocean 39
South polar ice cap
Structure of Mars 43
Surface of Mars 42
South Pole
Atmospheric circulation and winds 300
Coriolis force 297
Earth 58
Jupiter 44
Mars 42
Mercury 54
The Moon 40
Neptune 50
Pluto 51
Pulsar 28
Saturn 46
Uranus 48-49
Venus 56
South rim 277
South seeking pole 517
South Temperate Belt 45
South Temperate Zone 45
South Tropical Zone 45
Space 300-301
Space probes 614-615
Space shuttle astronaut 613
Space shuttle remote manipulator system (robot arm) 612, 613
Space telescope 612-613
Spadix 145
Span 484
Spandrel
Gothic church 471
Islamic building 488-489
Neoclassical building 482
Nineteenth-century

building 495
Renaissance building 474
Spanish bowline 389
Spar
BAe-146 jetliner components 415
BE 2B tail 405
Concorde, the 417
Pegasus Quasar ultralight 427
Spare tire 337, 339
Spare wheel well 341
Spark plug 342-343, 410
Spark plug cap 366
Spark plug hole 346
Spark plug lead 344
Spar trunnion 409
Spat 426-427
Spathe 145
Horsetails 120
Spawn 182-185, 192
Speaker
Digital video 583
Electronic music system 521
Headphones 586
System unit 567
Speaker assembly 580
Speaker plug 591
Speak key 590
Spear 382
Spear head 109
Specimen 610, 611
Specimen airlock 611
Specimen stage 610, 611
Spectral absorption lines 22-23
Spectral type 22-23
Specular hematite 268
Speech 257
Speed
Forces 320
Gearbox 366
Speedball nib 444
Speedometer 362
Speedometer drive 565
Sperm 258-259
Spermatheca
Snail 177
Spider 170
Sperm cell 217, 607
Sperm duct 195
Spermoviduct 177
Sperm whale 204-205
Sperry-ball gun turret 408
Sphenethmoid bone 183
Sphenoidal fontanelle 220
Sphenoidal sinus 212, 245
Sphenoid bone 220
Sphenopsids 279
Sphenopteris latiloba 72
Sphere 623
Spherical umbel 145
Spheroid 623
Sphincter muscle
Anal 249
Iris 241
Pyloric 249
Sea anemone 167
Urelhral 257
Sphyrna lewini 179
Spica 18, 21
Spicule 32, 33
Spieules 166
Spider
Arachnid 170-171
Bicycle 338, 360
Spider seat 334
Spigot 387
Spike
Aechmea miniata 162
Dodder 163
Double bass 511
Flower 143
Grape hyacinth 155
Thyreophorans 92-93
Volleyball 334
Spiky cupule 150
Spinal column 258
Spinal cord
Bird 189
Bony fish 181
Chimpanzee 202
Dogfish 179
Dolphin 205
Domestic cat 195
Elephant 200
Human 212, 217, 225, 256, 258, 261
Lizard 185
Rabbit 196
Spinal ganglion 223, 238, 243
Spinal nerve 223, 238
Spindle 601
Spine
Aechmea miniata 162
Barberry 130-131
Bromeliad 113
Calligraphy character 445
Cnidoeyte 167
Diatom 116
Drvland plants 156
Golden barrel cactus 156
Hemal 180
Herbaceous flowering plants 128-129
Human 218, 222-223
Mahonia 130-131
Modern jetliners 413, 415
Neural 180
Sea urchin 174
Starfish 174
Spine end fairing 421
Spinner
ARV light aircraft 424-425
Hawker Tempest components 408
Hawker Tempest fighter 409
Lockheed Electra airliner 407
Turbofan engine 418
Spinneret 170-171
Spinner mounting disc 406
Spinning lure 562
Spinose-dentate margin 129
Spinous process 222-223
Spiny anteaters 206
Spiny leaflets 130-131
Spiracle
Acanthostega 80
Caterpillar 169
Spider 170
Spiral arm
Galaxies 12-15
Milky Way 14
Spiral ganglion 243
Spiraling clouds 302
Spiraling low-pressure cells 302
Spiraling rain 305
Spiraling winds 302-305
Spiral scroll 460
Spiral spring 449
Spiral staircase 472, 476
Spiral tubes 342
Spiral valve 179
Spiral wrack 116
Spire
Asian building 490-491
Gothic church 470-471, 475
Medieval building 466, 468
Ninetee nth-century building 493
Renaissance building 476-477
Spirit lamp 454
Spirketting 381
Spirogyra sp. 117
Spit 291
Splayed window-sill 475, 482
Spleen
Bony fish 181
Chimpanzee 202
Domestic cat 195
Elephant 200
Frog 182
Human 215, 249
Splenic artery 255
Splicing fid 383
Splint bone 198
Splinter bar 335
Splintery fracture 270
Split flap 406
Split line 151
Split-open pollen sac 144
Split rudder 421, 572
Spoiler 546, 349
Spoiler anchorage 413
Spoiler arm 414
Spoke
Bicycle wheel 358-359
Bordino Steam Carriage 335
Eddy Merckx racing bicycle 361
Etching press 447
Paddle wheel 391
Ship's wheel 390
Spoked wheel
Bievcle 358-359
Pacing sulky 555
Spoke guard 358
Spoke nipple 361
Sponge roller 442
Sponges 166-167
Fossils 279
Spongocoel 166
Spongy bone 224
Spongy mesophyll 126, 139
Spongy tissues 156
Spool 562
Spoon 560
Spoon-shaped tooth 91
Sporangia 120-121
Sporangiophore 120
Sporangium 79
Spore-case 79
Spore-producing structures
Fern 121
Fungi 114-115
Lichen 114
Moss 112
Spores
Clubmoss 120
Fern 120-121
Fungi 114-115
Horsetail 120
Lichen 114
Liverworts 118
Mosses 1 18-119
Mushroom 115
Sporophores 114-115
Sporophyles
Clubmoss 120
Fern 120-121
Horsetail 120
Liverworts 118
Moss 112, 118-119
Sports tire 365
Sports wheel 340
Sprag clutch 410
Spray and steam knobs 594
Spray barrel 594
Spray nozzle 594
Spray pump 594
Spreader 561
Spring
Lakes and Groundwater 292
Motorcycle 366
Power drill 600
Toaster 599
Spring and chassis unit 337
Spring balance 320
Springboard diving 558
Spring/muffler unit 365
Springing point 467, 484-485
Spring line 292
Spring perch 338
Spring petiole 160
Spring shock absorber 338-339
Spring tides 296-297
Spring-trap mechanism 160
Spring washer 601
Spring wood xylem 134
Sprint races 560
Sprinting 542
Sprilsail 378
Sprit yard 376
Sprocket 358, 366
Spruce 513
Spruce beam 560
Sprung chassis 334
Spunyarn 388
Spun yarn serving 383
Spur 169
Spur gear 574
Spurious wing 191
Squadron code 409
Squamala 184
Squamosal bone 183
Squamous suture 220
Squainulose lichens 114
Squamulose thallus 114
Square 622
Square cut 538
Square knot 388
Square leg 538
Square-leg umpire 558
Square masonry 465
Square rib 486
Square-rigged ship 375
Square sail 374, 378, 384
Square-section steel tubing 364
Square-section tire 362, 369
Squash 544, 545
Squeegee 448
Squid 176
Squinch 466
Squirrel 196-197
Squirrel hair brush 458
Squirrel mop wash brush 438
SST 416-417
St. John's wort 145
St. Basil's Cathedral 487
St. Paul's Cathedral
Arch 484
Baroque style 478, 480-481
Dome 480, 486-487
Old 470, 472
Stabilizer 397, 548
Stabilizer-bar weight 422
Stabilizer fin 396
Stable elements 310, 311
Stack 295
Staff 377, 396
Stage 477, 495
Stage-door 477
Stained glass 470
Stainless steel cover 599
Staircase
Ancient Roman building 465
Baroque church 481
Gothic church 470, 472
Medieval building 466
Modern building 496-497, 499
Neoclassical building 483
Renaissance building 474-477
Staircase turret 468
Stairs 477
Stair tool 593
Stairway 489
Stalactites 284-285
Stalagmites 284-285
Stalagmitic boss 284
Stalagmitic floor 284
Stalk
Algae 116
Barnacle 173
Dicotyledons 127
Flower 140
Fungi 114-115
Liverwort 118
Monocotyledons 128
Moss 112, 119
Pitcher plant 113
Seaweed 117
Stem succulent 113
Water lily 159
Stalked barnacle 173
Stalked secretory glands 161
Stalk scar 123
Stall warning vane 412
Stamen remains 146-147, 150
Stamens 140-143
Anther 140-143
Dicotyledon flower 126-127
Fertilization 146-147
Filament 140-145
Insect-pollination 144
Monocotyledon flower 126
Rose 131
Stamp 445
Stance
Dinosaurs 82
Hominids 108
Westlothiana 81
Stanchion 373, 393
Standard 554
Standardized horse 554, 555
Standard European paper 445
Standard knee 381
Standby pitot head 416-417
Standing block 382
Standing lug mizzen 385
Standing part
Hawser bend 387
Rigging 382-383
Single sheet bend 387
Standing position 348
Standing rigging 382-385
Standoff half 530
Stapes 242
Staple 449
Starbirlh region 16
Starboard side 374
Starch grains 139
Chlamydomonas sp. 116
Orchid root 133
Star clusters 16-17, 615
Objects in universe 11
Our galaxy and nearby galaxies 14
Star coral 167
Star drag 562
Star dune 283
Starfish 174-175
Fossil 79
Star formation in Orion 24
Starling 467
Star magnitudes 22
Stars 22-25, 613
Massive stars 26-27
Milky Way 14-15
Neutron stars and black holes 28-29
Small stars 24-25
Star clusters 16, 613
Sun 32-35
Star scanner 615
Star-shaped parenchyma 135
Star-shaped sclereids 159
Stars of northern skies 18-19
Stars of southern skies 20-21
Starter 339, 558
Starter cog 336
Starter motor
Hawker Tempest components 408
Mid West twin-rotor engine 411
Renault Clio 351
Volkswagen Beetle 340
Starter ring 345
Starling block 558
Starting handle 336-337, 338, 343
Starling line (100m) 542
Start print button 575
Stale room 392
Static air-pressure plate 412
Static discharge wick 406
Static electricity 316
Stationary gear' 346-347, 411
Slalor 410
Statue 472, 478
Statue creation 455
Statuette 476, 481
Status indicator 577
Staurikosaurus 69
Stay 325, 392
Staysail 378, 383
"Stealth" bomber 420-421
Steam 275, 507
Locomotives 324, 325
Nuclear power station 314
Oil-fired power station 315
Steam barrel 594
Steamboat with paddle wheels 391
Steam car 334, 342
Steam chest 334
Steam chest pressure gauge 325
Steam condenser 397
Steam control knob 394
Steam dome 325
Steam engine 390-391
Steam generator 314
Steam grating 380
Steam iron 594
Steam launch 394
Steam locomotive 324, 325
Steam pipe 334-335
Steam pipework 397
Steam-powered Cugnol "Fardier" 334
Steam release activator 594
Steam whistle 392
Steel 492
Steel and concrete floor 498
Steel and titanium skin 416
Steel beater 517
Steel brace 493
Steel column 497-498
Steel floor-plate 497
Steel frame 360, 364
Steel girder framework 314
Steel lattice-beam 497
Steel lock 360
Steel mullion 494
Steel point 432
Steel rails 330
Steel-reinforced concrete 494

Steel sleeper 330
Steel wheel 340, 350-351
Steeple 471, 481
Steeplechase 554
Steep ridge 283
Steerboard side 374
Steerer tube 359
Steering 350, 364
Steering actuator 416
Steering arm 338-339
Steering box assembly 340
Steering column
Benz Motorwagen 335
Ford Model T 339
Renault Clio 350
Volkswagen Beetle 341
Steering gear 392
Steering gearbox 339
Steering head 335
Steering idler 340
Steering knuckle 338
Steering link 335
Steering oar 374
Steering pump pulley 344
Steering rack 335, 350
Steering spindle 336
Steering stop 425
Steering tie-rod 340
Steering tiller 334-335, 337
Steering track-rod 337
Steering wheel
1906 Renault 337
Ford Model T 338-339
Renault Clio 350, 353
White Steam Car 342
Steering wiffletree 337
Stegoceras 100-101
Stegosauria 83
Stegosaurus 71, 92
Steib chair 362
Stela 459
Stele
Dicotyledons 127
Monocotyledons 127
Root 132-133
Stellar core 17
Stellar spectral absorption lines 22-23
Stellate parenchyma 135
Stem 134-135
Aechmea miniata 162
Asteroxylon 79
Bamboo 131
Barberry 130-131
Battleship 394
Begonia 129
Bishop pine 124-125
Brassavola nodosa 162
Bromeliad 113
Broomrape 163
Calligraphy character 445
Canadian pond weed 158-159
Chusan palm 130
Clubmoss 120
Corallina officinalis 117
Couch grass 113
Crab cactus 129
Dicotyledons 126-127
Dodder 163
Eddy Merckx racing bicycle 361
Epiphytes 162-163
Everlasting pea 129
Florists' chrysanthemum 129
Flower arrangements 143
Golden barrel cactus 156
Guzmania lingulata 162-163
Hogweed 129
Horsetail 120
Ice-plant 128-129
Iron paddlesteamer 393
Ivy 131
Kedrostis africana 113
Live-forever 128-129
Liverwort 118
Maidenhair tree 123
Maple 127
Monocotyledons 126-127
Moss 119
Parasitic plants 163
Passion flower 130
Peach 131
Perennials 130-131
Sago palm 123
Strawberry 128
String of hearts 157
Vegetative reproduction 154-155
Water fern 158
Welwitschia 123
Woody plants 130-131
Woody stem 134
Yew 123
Stem bases
Bulbil 155
Guzmania lingulata 162-163
Stem branch 129
Stem bulbils 155
Stem cambium 126
Stem cells 606, 607
Stem head 376
Stempost
74-gun ship 381
Dhow 376
Longboat 380
Sailing warship 376
Viking ships 374-375
Stem projections 156
Stem segments 129
Stem succulents 113, 156-157
Stem tubers 128, 154
Stencil 446
Step
74-gun ship 381
ARV light aircraft 424
BE 2B bomber 404
Blériot XI monoplane 401
Medieval building 467
Modern building 499
Neoclassical building 483
Steam-powered Cugnot 334
Twentieth-century building 495
Wooden sailing ship 378
Stephenson, Robert 324
Stepped roof 481
Stepped stempost 375
Stepped sternpost 375
Sterile hairs 117, 119
Sterile ray 119
Sterile ray floret 142
Sterile shoot 120
Sterile whorl 116
Stern
74-gun ship 381
Iron paddlesteamer 392
Kayak 560,
Sailing dinghy 561
Wooden sailing ship 378-379
Sterna hirundo 193
Sternal artery 173
Sternal bone 96, 102
Stern balustrade 373
Stern carving 381
Stern framing 392
Stern gallery 397
Stern lantern 379
Sternocleidomastoid muscle 226-227, 229
Sternohyoid muscle 229
Sternpost
Greek galley 372
Roman corbita 373
Sailing warship 377
Single scull 560
Viking ships 374-375
Wooden sailing ship 378
Stern quarter gallery 379
Stern rope 387
Stern section 392
Sternum
Bird 189
Domestic cat 195
Elephant 201
Hare 197
Horse 199
Human 218
Kangaroo 206
Seal 204
Stern walk 395
Stibnite 268
Stick insect 192
Stiff brush 436
Stifle 198
Stigma
Damselfly 168
Dicotyledon flower 126-127
Fertilization 146-147
Flower 140-143
Pollination 144-145
Stigma remains 146-147, 150-151
Stilt 494
Stilted arch 468
Sting 170
Stinging cells 166
Stinkhorn 114
Stipe 114-115, 116-117
Stippled effect 442
Stipule
Begonia 129
Everlasting pea 129
Passion flower 130
Rose 131
Seedling leaf 152
St. John's wort 145
Strawberry 128
Stirrup
Crossbow 548
Ossicles of middle ear 242
Saddle 555
Stoa 460
Ancient Roman building 463, 465
Islamic building 488
Stock
74-gun ship 380
Danforth anchor 386
Roman anchor 372
Stockless anchor 386
Stöfler 40
Stoker's seat 334
Stolons 154
Stomach
Barnacle 173
Bird 189
Bony fish 181
Chimpanzee 202
Cow 198
Crayfish 173
Dogfish 179
Dolphin 205
Domestic cat 195
Elephant 200
Frog 182
Human 214, 248
Jellyfish 167
Lizard 185
Octopus 176
Babbit 196
Ruminants 198
Snail 177
Starfish 174
Tortoise 187
Stomach throw 556
Stomata
Dryland plants 156-157
Golden barrel cactus 156
Haworthia truncata 157
Monocotyledon leaf 126
Photosynthesis role 138-139
Pine needle 124
Wetland plants 158
Stone
Succulent fruits 148
Lithographic printing 446, 448
Sculpture 452
Stone canal 174, 175
Stone plate 446, 448
Stony-iron meteorite 52
Stony meteorite 52
Stop lamp assembly 352
Stop signal 330
Stopwatch 524
Storage locker 572
Storage organs
Bulb 155
Corm 155
Rhizome 155
Scale leaf 155
Seed 152
Succulent tissue 156-157
Swollen stem 113, 155
Tubers 128, 155
Underground 154-155
Storage unit 573
Store button 521
Stores pylon 420-421
Stork 188
Storm 303
Straddle wire 358, 359
Straight 555
Straight four cylinder arrangement 345
Straight gouge 452
Straight handlebar 361
Strake
Concorde 416-417
Ironclad 393
Roman corbita 372
Viking ships 374-375
Strapontin 337
Strap-shaped leaf 162
Strata 276
Faults and folds 60-61
Sedimentary rocks 276
Stratocumulus cloud 302
Stratosphere
Earth's atmosphere 300-301
Jupiter's atmosphere 45
Mars' atmosphere 43
Saturn's atmosphere 47
Stratum basale 235
Stratum corneum 235
Stratum granulosum 235
Stratum spinosum 235
Stratus cloud 302
Strawberry 128, 150
Straw butt 549
Streak 270-271
Stream
Glaciers 286-287
Groundwater system 293
Spring examples 292
Streamed internet radio on-screen display 577
Streamed internet video on-screen display 577
Streamlined spinner 407
Strengthening tissue
Fern rachis 121
Horsetail stem 120
Marram grass 113
Monocotyledon leaf 126
Stems 134-135
Water lily leaf 159
Stress 61
Stretcher
Brickwork 485
Nineteenth-century building 492
Single scull 560
Stretches 555
Striated effect 442
Striation 46
Strike
Baseball 536
Baseball umpire signal 537
Slope structure 60
Striker 524
Strike-slip fault 61
Strike-slip fault lake 293
Strike zone 536
Strindberg 35
String
Acoustic guitar 512-513
Cello 511
Concert grand piano 515
Double bass 511
Electric guitar 513
Harp 511
Upright piano 514
Viola 511
String arm 511
String course
Ancient Roman building 465
Cathedral dome 487
Medieval building 466-467
Nineteenth-century building 493
Stringed instruments 510, 511
Guitar 512, 513
Orchestral arrangement 504, 505
Strings
Guitar 512-513
Racket 544
Violin 510
Strix aluco 190
Strobili 120
Stroke judge 558
Stroke play 546
Strokes 546
Stroke-side oar 560
Stroma 139
Stroma thylakoid 139
Strongylocentrotus purpuratus 175
Strontium 310
Strop 383
Strut
Dome 484, 486
Gothic building 473
Marble sculpture support 453
Neoclassical building 479
Paddlesteamer 390
Timpanum 519
Strut insert 340
Struthio camelus 188
Egg 193
Struthiolaria 279
Struthiomimus 84, 87
Stub axle 424
Stud
Ancient Roman mill 464
Gothic building 473
Mid West single rotor engine 410
Studding sail boom 378
Studding sail yard 378
Studio Elvira 495
Study 477
Stuffing box 390
Stump
Coastline 295
Wicket 538
Stupa 490-491
Stupica 491
Sturgeon 180
Style 140-143
Fertilization 146-147
Monocotyledon flower 126
Pitcher plant 113
Pollination 144-145
Rowan fruit 131
Style of the gnomon 377
Style remains
Dry fruit 150-151
Fruit development 146-147
Succulent fruit 148-149
Stylet 167
Stylobate 460
Styloglossus muscle 244
Styloid process 220, 243
Styracosaurus 102, 103
Subacute leaf apex 136-137
Subarachnoid space 237
Subclavian artery 215, 251, 253
Subclavian vein 253
Subduction 58
Subduction zone 281
Subframe 351
Subgenital pit 167
Subglacial stream 287
Sublimation 307
Sublingual fold 245
Sublingual gland 244-245
Submandibular gland 244
Submarine 396-397
Submarine canyon 298
Submerged atoll 299
Submerged glacial valleys 294-295
Submerged river valleys 294
Subopercular bone 181
Substitutions 532, 550
Substomatal chamber 139
Substrate 112
Substratum 115
Subsurface current 297
Subtropical jet stream 300
Subwoofer 586
Succulent fruits 148-149, 150
Bramble 130
Development 146-147
Peach 131
Rowan 131
Succulent leaves 128, 157
Succulent plants 156-157
Succulents 112
Leaf 157
Stem 156-157
Stem and root 157
Trailing stem 157
Succulent stem 129
Sucker
Lamprey 178
Octopus 176
Sucking stomach 170
Suction reduction control 593
Sugar
Fermentation 312
Formation 138
Photosynthesis 315
Transport 139
Sulcus terminalis 244
Sulfates 269, 296
Sulfides 268
Sulfur 39, 268
Periodic table 311
Sulfur dioxide 37
Sulfuric acid 36-37
Sulfurous gases 273
Sulky 554-555
Sumatra 265
Sumigi 490
Summer petiole 160
Summit caldera 42
Sump 343, 344-345
Sump pan 354
Sun 32-33, 38
Atmosphere 301
Comet tails 48
Earth's energy 314
Electromagnetic radiation 314-315

Energy emission from Sun 22
Light 318
Milky Way 14
Objects in universe 11
Oceans and seas 296-297
Ozone formation 64
Solar eclipse 32
Solar system 30-31
Stars 22-23
Sun blind 573
Sundew 160
Sundial 376, 377
Sunflower 140, 142, 145
Sunken stoma 157
Sunlight and photosynthesis 138
solar power 605
Sun roof 341
Sun scoop 498
Sun sensor 614
Sunspots 32-33
Sun visor 350, 353
Supai group 277
Superclusters 10
Supercooling 307
Supercool liquid 306-307
Superficial peroneal nerve 238
Superficial skeletal muscles 226-227
Superfluid neutrons 28
Super-giant slalom (Super-G) skiing 552
Supergiant stars
Massive stars 26
Stars 22-23
Stellar black hole 29
Supergranule 33
Superheater 325
Superior articular facet 222
Superior articular process 222-223
Superior concha 212
Superior laryngeal nerve 244
Superior longitudinal muscle 245
Superior meatus 245
Superior mesenteric artery 253, 256
Superior mesenteric trunk 257
Superior mesenteric vein 253
Superior nasal concha 245
Superior oblique muscle 241
Superior orbital fissure 221
Superior ramus of pubis 224, 257
Superior rectus muscle 241
Superior sagittal sinus 212, 237
Superior thyroid artery 244
Superior vena cava 215, 251, 252-253, 255
Supernova
Massive stars 26-27
Nebulae and star clusters 16
Neutron stars and black holes 29
Supernova remnant
Nebulae and star clusters 16-17
X-ray image of Crab Nebula 28
Supersonic flight 416
Supersonic jetliners 416-417
Supersonic transport 416-417
Supporter 381
Supporting tissue
Bishop pine stem 125
Dicotyledon leaf 126
Stems 134-135
Supraesophageal ganglion 173
Supraoccipital bone 181
Supraoccipital crest 84
Supraorbital fissure 221
Supraorbital foramen 221
Supraorbital margin 213, 220, 221
Supraorbital notch 213
Supraorbital ridge
Chimpanzee 202
Stegaceras 100
Styracosaurus 102
Suprarenal gland 257
Suprarenal vein 257
Suprascapula 183
Suprasternal notch 211
Surangular bone 102
Surcingle loop 555
Surface areas 623
Surface currents 296-297
Surface deposits 273
Surface layer 293
Surface ocean current 296
Surface streams 284
Surface temperature 39
Stars 22
Structure of main sequence star 24
Structure of Mars 43
Structure of Mercury 35
Structure of Neptune 51
Structure of red giant 25
Structure of red supergiant 26
Structure of Venus 37
Sun 33
Surface terrain 284
Surface vegetation 282
Surface winds 300
Surrogate mother 607
Surround sound 584
Surround sound special effect plug-in 521
Surveillance RADAR 397
Suspended erratic 286
Suspension
"Deltic" diesel-electric locomotive 327
Motocross racing 368
Motorcycle 364
Ultralight 426
Suspension arm 350-351
Suspension linkage 362
Suspension spring 350
Suspension strut 340, 351
Suspension top mount 340
Sustaining pedal 514, 515
Suture 202
Su-wei 376
Suzuki RGV500 368, 369
Swab hitch 387, 389
Swallow 383
Swallow-hole 284
Swamp 290-291
Swan neck ornament 373
Swash plate 344
Swash zone 294
S waves 63
Sweat duct 235
Sweat gland 234-235
Sweat pore 234-235
Sweep rowing 560
Sweep-rowing boat 561
Sweeping low throw 556
Sweet chestnut 136, 144, 150
Sweetgum 76
Sweet pea 128
Sweet potato 154
Swell manual 514
Swell of muzzle 395
Swell pedal 514
Swell stop 514
Swept titanium fan blades 572
Swifting tackle 377
Swim bladder 178, 180-181
Swimmeret 172
Swimming 558, 559
Swimming pool 558
Swimwear 558
Swingarm 364, 368
"Swing-wings" 420
Switch 316
Switchboard room 397
Switch end casting 598-599
Switch gear 314
Swivel becket 382
Swivels
Mooring and anchoring 386
Angling 562, 563
Swivel suspension ring 377
Swollen leaf base 154-155
Swollen stem base
Guzmania lingulata 163
Kedrostis africana 113
Oxalis sp. 157
Swollen stem 154-155
Sword 556-557
Sycamore 131, 150-151
Sycamore beam 560
Syconium 148
Syenite 275
Symbiosis
Lichens 114
Mycorrhizal association 133
Symbols
Biology 591
Chemistry 591
Communication 108
Mathematics 591
Music 502, 503
Physics 591
Symphony orchestra 504, 505
Synapsid reptile skull 67
Synaptic knob 228, 239
Synaptic vesicle 239
Sync port 587
Syncarpous gynoecium 140
Synchiropus splendidus '180
Synchronized elevator 423
Syncline 60, 61, 62
Synclinorium 61
Synergid nucleus 147
Synsacrum 189
Synthesizer 520
Synthetic brush 436, 438
Synthetic flax 384
Synthetic hog hair brush 442
Synthetic materials 306
Synthetic polymer 306
Synthetic resin 442
Synthetic ropes 388
Synthetic sable brush 442
Synthetic strings 544, 545
Synthetic wash brush 438, 442
Syria Planum 42, 43
System display 573
Systems connector 413
System unit 567

T

Tabernacle 463, 474, 476
Tab hinge 415
Tablet computer 568-569
Tablet flower 488, 491
Tabling 372, 384
Tabular habit 271
Tacan aerial 420
Tachybaptus ruficollis 190
Tack 375
Tackling
Australian rules football 528, 529
Football 526
Rugby 531
Soccer 524
Tactical air navigation (Tacan) aerial 420
Tadpoles 182-183, 192
Taenia 460
Taenia colica 249
Taffrail 378, 381
Tail
Amphibian 182
Anchisaurus 89
BE 2B bomber 404
Caiman 187
Calligraphy character 445
Corythosaurus 98
Crocodilians 186
Deer hopper dry fly 563
Dolphin 205
Dunkeld wet fly 563
87
Hare 196
Hawker Tempest components 409
Herrerasaurus 86
Horse 198
Ichthyostega 80
Iguanodon 96
Iguanodonts 96
Kangaroo 206
Lion 195
Lizard 184-185
Lungfish 81
Monkey 202
Ornithopods 96
Pachycephalosaurus 100
Prehensile 202
Rabbit 196-197
Rat 196
Rattlesnake 185
Rigging 382-383
Salamander 182
Sauropodomorpha 88
Schweizer helicopter 423
Scorpion 170
Ski 552-553
Stegoceras 101
Stegosaurus 93
Tadpole 183
Triceratops 102
Tyrannosaurus 84
Westlothiana 81
Tail area 78
Tail boom 423
Tail bud 260
Tail bumper 417
Tail club 95
Tail cone 416-417, 418
Tailcone fairing 572
Tail crest 187
Taileron 420-421
Tail fairing 409
Tail feathers 188
Tail fluke 205
Tailgate 348
Tail gunner's compartment 408
Tail-gun turret 408
Taillight
BMW R/60 362
Harley-Davidson FLHS Electra Glide 362
Honda CB750 363
Vespa Grand Sport 160
Mark 1 363
Tailpiece 510, 511
Tail-pin 510
Tail pipe 340
Tailplane
Airbus 380 572
ARV light aircraft 424
BAe-146 jetliner 415
BK 2B tail 405
Biplanes and triplanes 402-403
Blackburn monoplane 401
Blériot XI monoplane 401
Curtiss biplane 399
Hawker Tempest 409
Lockheed Electra airliner 407
Schleicher glider 426
Tailplane fairing 415
Tailplane root 409
Tailplane tip 407, 415
Tailrace 314
Tail rod 390
Tail rotor 422-423
Tail-rotor drive shaft 422, 423
Tail rotor gearbox 423
Tail shield 78
Tailskid
ARV light aircraft 424
Avro triplane 403
BE 2B bomber 405
Blackburn monoplane 400-401
LVG CVI fighter 405
Tail spike 92
Tail spine 79
Tail unit 368
Tailwheel
Avro biplane 402
B-17 bomber 408
Hawker Tempest fighter 409
Lockheed Electra airliner 407
Schleicher glider 426
Tailwheel leg 401
Takeoff and landing skid 398
Takla Makan Desert 265
Talc 270-271
Tallow coating 379
Talonavicular ligament 232
Talons 188
Talus 282-283
Talus bone 232
Tamarins 202, 203
Tambourine 504, 518
Tam-tam 504, 516
Tandem wings 402
Tank 392
Tank drain tap 407
Tank inspection access 417
Tank support 339
Tantalum 310
Tantalus Fossae 43
Tapeats sandstone 277
Tapir 198
Tappet 343
Tappet adjustor 367
Tap root 128
Tarantula Nebula 26-27
Large Magellanic Cloud 12
Tarantulas 170-171
Target areas 556, 557
Target hole 546
Target pistol 548, 549
Target shooting 548, 549
Tarn 293
U-shaped valley formation 287
Tarsal bone
Albertosaurus 84
87
Iguanodon 97
Tarsals
Crocodile 186
Domestic cat 195
Elephant 201
Frog 183
Hare 197
Horse 199
Kangaroo 206
Lizard 184
Platypus 206
Rhesus monkey 202
Seal 204
Tarsiers 202
Tarsomere 13
Tarsometatarsus 189
Tarsus
Beetle 168
Bird 188
Human 219
Scorpion 170
Spider 171
Tas-de-charge 469
Tasmanian devil 207
Taste 244
Taste bud 244
Tau Orionis 18
Taurus 19, 20
Taurus mountains 77
Tau Sagittarii 21
Tawny owl 190
Taxiing light 414, 420
Taxus baccata 70, 123
Tea clipper 392
Team crest 531
Team jersey 529
Team name 533
Tear fault 61
Technetium 310
Technosaurus 69
Tee 546
Teeing ground 546
Tee peg 547
Teeth
Ankylosaurus 92
Bear 106
Caiman 186
Canine 194, 202
Carnassial 194
Carnivores 194
Ceratopsian 100
Cheek 194
Chimpanzee 202
Crocodilians 186
Extinct shark 67
Hadrosaur 96
Hominid 108
Horse 105
Human 246-247
Iguanodont 96
Incisor 194, 196, 201, 202
Lamprey 178
Leaf-shaped 88-89
Molar 194, 201, 202
Ornithopod 96
Premolar 194, 202
Rabbit 196
Rodents 196
Theropod 84
Thyreophoran 92
Venus fly trap 160
Teeth development 246
Tegenaria gigantea 171
Telephone line 576
Telescope, space 612-613
Telescopic fork
Harley-Davidson FLHS Electra Glide 363
Honda CB750 363
Honda VF750 364
Husqvarna Motocross TC610 368
Motorcycle 364
Suzuki RGV500 368
Weslake Speedway motorcycle 369
Telescopic muffler 326, 329
Telescopic sight 548, 549
Telescopic strut 416
Television 315
Telltale 545

Tellurium 311
Tellus Regio 36, 37
Tellus Tessera 37
Telson 172
  Fossil 79
TEM 610, 611
Tempe Fossae 43
Tempera 432, 433
Temperate latitudes 302
Temperature
  Atmosphere 300-301
  Chemical reactions 312-313
  Formation of black hole 29
  Germination 152
  Matter 306-307
  Mineral resources 280
  Oceans and seas 296
  Stellar black hole 29
  Weather 302-303
Temperature and pressure sensor 418
Temperature and steam control dial 594
Temperature changes
  Atmosphere 301
  Oceans and seas 296
  Weathering and erosion 282
Temperature scales 621
Tempered pigment 432
Temple 484-485
  Ancient Egyptian 458
  Ancient Greek 460-461
  Ancient Roman 462-463
  Asian 490
Temple blocks 516
Temple Butte limestone 277
Temple Cap sandstone 276
Temple of Amon-Re 458-459
Temple of Aphaia 461
Temple of Athena Polias 460
Temple of Heaven 490
Temple of Isis 459
Temple of Mallikarjuna 491
Temple of Neptune 460-461
Temple of Vesta 462-463
Temple of Virupaksha 490-491
Tempo 504
Temporal bone
  Chimpanzee 202
  Human 220-221, 242
Temporal lobe 257
Temporalis muscle 226-227, 229
Tendon
  Achilles 232-233
  Annular 241
  Calcanean 232-233
  Extensor digitorum longus 233
  Extensor digitorum 231
  Extensor hallucis longus 233
  Flexor digitorum 231, 87
  Palmaris longus 231
  Peroneus brevis 233
Tendril
  Arabesque 480
  Clematis 130
  Dogfish egg 192
  Everlasting pea 129
  Monkey cup 161
  Passion flower 130
Tennis 544
Tennis racket 544
Tenon
  Flax spinning mill 492
  Hull plank fastening 373
Tenor drum 518-519
Tenor joint 508
Tenor mule 507
Tenor note strings 515
Tenor saxophone 509
Tenor voice 502
Tension
  Drums 518
  Faults and folds 60-61
  Mountain building 62
Tension column 497
Tension control 552
Tension key 518, 519
Tension member 499
Tension pulley 360
Tension rod 518, 519
Tension screw 518
Tensor fasciae latae muscle 226
Tensor tympani muscle 243
Tentacle
  Coelentrates 166
  Jellyfish 167
  Mollusks 176-177
  Scallop 176
  Sea anemone 166-167
  Snail 177
Tenth century
  Building 490
  Style 468
Tepal scar 140
Tepal
  Flower parts 140, 143
  Monocotyledons 126
  Peruvian lily 129
Terbium 311
Teres major muscle 227
Teres minor muscle 227
Tergum plate 175
  Egg 193
Terminal box 317
Terminal bronchiole 254
Terminal bud
  Bishop pine 124
  Horse chestnut 130
  London plane 134
  Rhizome 155
  Root tuber 154-155
  Stems 154
  Stolon 154
Terminal ileum 249
Terminal lake 286
Terminal moraine
  Glaciers 286
  Rivers 289
Terminal pinna 136
Terminal ring 259
Terminus 286
Terrace
  Asian building 490-491
  Modern building 497-499
  Twentieth-century building 494-495
Terracotta clay 455
Terrain-following radar 420
Terrapin 186-187
Terrestrial animal 74
Terrestrial mammal 104
Terrigenous sediment 299
Tertiary bronchus 215
Tertiary period 57, 74, 75
  Fossil record 279
Tessellation 489
Tessera 450, 489
Test 174-175
Testa 152
  Dry fruit 150-151
  Embryo development 147
  Epigeal germination 153
  Hypogeal germination 152
  Succulent fruit seed 148-149
Testicle 259
Testicular artery 257
Testicular vein 257
Test is
  Barnacle 173
  Dolphin 205
  Domestic cat 195
  Human 259
  Rabbit 196
Test tube 313
Tetanurae 83
Tethus Regio 36
Tethys 46
Tethys Sea
  Cretaceous period 73
  Jurassic period 71
Tertiary period 74, 75
  Triassic period 69
Tetragonal system 270
Tetrahedron 623
Tetralophodon 75, 104
Text 444
Textured papers 441
Textured scraper 593
TGV electric high-speed train 329
Thalamian 373
Thalamus 236-237
Thalassiosira sp. 116
Thalictrum delavayi 137
Thallium 311
Thalloid liverwort 118
Thallus
  Algae 116-117
  Lichen 114
  Liverwort 118
  Seaweed 116-117
T-handle auger 374
Thar Desert 265
Tharsis Tholus 43
Thatched roof 477
Thaumasia Fossae 43
The Big Dipper 19
Themis Regio 36
Therapeutic cloning 606
Theobroma cacao 148
Therapsids 104
Thermal/electrical insulation 596, 597
Thermal insulation 613
Thermals 426
Thermocouple bus-bar 419
Thermogram 214
Thermosphere
  Earth's atmosphere 300
  Mars' atmosphere 43
  Venus' atmosphere 37
Thermostat 411
Theropoda 83
Theropods 84-87
Thesium alpinium 145
Theta1 Sagittarii 21
Theta Andromedae 19
Theta Pegasi 19
Thetis Regio 36
Thick skull 46
Thigh
  Anchisaurus 89
  Bird 188
  Corythosaurus 98
  Gorilla 203
  Horse 198
  Human 211
  Iguanodon 96
  Kangaroo 207
  Lion 195
  Psittacosaurus 103
  Stegoceras 101
  Stegosaurus 92
  Triceratops 102
  Tyrannosaurus 84
Thigh musculature 90
Thigh pad 527
Thimble
  Harness racing 555
  Rigging 383, 384
Third-century building 465
Third home 541
Third man 538, 541
Third rail 528
Third stage motor 615
Thirteenth century
  Building 467, 469-471
  Style 470
Thirty-five mm file strip holder 570
Thistle funnel 313
Thole pin 380
Thoracic cavity 255
Thoracic leg 169
Thoracic nerve 238
Thoracic pleurae 78
Thoracic segment 79
Thoracic vertebrae
  Crocodile 186
  Domestic cat 195
  Hare 197
  Horse 199
  Human 222
  Kangaroo 206
  Platypus 206
  Rhesus monkey 202
  Seal 204
Thoracolumbar vertebrae
  Elephant 201
  Lizard 184
Thorax
  Cirripedia 172
  Human 211
  Insects 168-169
Thorium 310
Thornback ray 179
Thoroughbred horse 554
Thranite 373
Thread 167
Three-blade main rotor 423
Three-cylinder Anzani engine 401
Three-cylinder engine 425
Three-lobed stigma 143
Three-masted square-rigged ship 375
Three-point line 532
Three pounder 395
Three-toed ungulates 198
Threshold 463
Throat
  Angling hook 562
  Bird 188
  Danforth anchor 386
  Human 212, 244-245
  Lacrosse crosse 541
  Racketball racket 545
  Squash racket 545
  Tennis racket 544
Throatlatch 199
Throttle
  Avro triplane 402
  Curtiss biplane 398
  "Rocket" steam locomotive 324
  Suzuki RGV500 363
  Vespa Grand Sport 160
  Mark 1 363
  Weslake Speedway motorcycle 369
Throttle butterfly 345
Throttle cable 350
  Harley-Davidson FLHS Electra Glide 363
  Husqvarna Motocross TC610 368
  Kirby BSA racing sidecar 369
  Suzuki RGV500 369
  Weslake Speedway motorcycle 369
Throttle lever 419, 425
Throttle linkage
  Ford Model T 338
  Jaguar V12 engine 345
  Oldsmobile trim 337
  Renault Clio 350
Throttle wheel 342
Throw
  Judo 556
  Structure of a fault 60
Thrower 594
Throw-in 532
Thrushes 188
Thrust 543
Thruster cluster 615
Thrust fault 61
Thrust plate 601
Thrust-reverser 421
Thulium 311
Thumb 211, 230-231
Thumb-claw
  Anchisaurus 89
  Apatosaurus 83
  Baryonyx 85, 85
  Massospondylus 83, 89
  Plateosaurus 88
Thumbhole 384
Thumb knot 389
Thumb piston 514
Thumb-spike 96-97
Thwart 373, 375, 380
Thylakoid 139
Thymine 216
Thyreophora 83
Thyreophorans 92-93, 94-95
Thyristor converter 328
Thyrohyoid membrane 244
Thyrohyoid muscle 229, 244
Thyroid cartilage 245, 255
Thyroid gland 214-215, 217, 244-245, 255
Tibetan plateau 63
Tibia
  Archaeopteryx 85
  Beetle 168
  Butterfly 169
  Crocodile 186
  Diplodocus 90
  Domestic cat 195
  Elephant 201
  Eryops 81
  Gallimimus 86
  Hare 197
  Horse 199
  Human 219, 232-233
  Iguanodon 96-97
  Kangaroo 206
  Lizard 184
  Parasaurolophus 99
  Plateosaurus 88
  Platypus 206
  Rhesus monkey 202
  Scorpion 170
  Seal 204
  Spider 171
  Stegoceras 101
  Stegosaurus 93
  Struthiomimus 87
  Toxodon 107
  Triceratops 102
  Turtle 187
  Tyrannosaurus 84
Tibiale 183
Tibial flexor muscle 97
Tibialis anterior muscle 226, 233
Tibialis posterior muscle 233
Tibiofibula 183
Tibiotarsus 189
Tidal bulge 297
Tidal currents 296-297, 298
Tidal flow 296
Tidal levels 295
Tidal power 604
Tidal river-mouth 295
Tidal scour 298
Tidal waves 58
Tides 294, 297
Tie
  Basketball match 532
Bordino Steam Carriage 334
  Musical notation 502, 505
  Tie-beam
  Ancient Roman mill 464
  Dome 486
  Gothic church 473
  Neoclassical building 479
Tie plate 393
Tierceron 485
Tie rod 334, 340
Tiger seat 334
Tiger shark 178-179
Tight end 526
Tight-head prop 530
Tile
  Dome 486
  Islamic mosque 488
  Modern building 499
  Neoclassical building 482
  Renaissance building 476-477
Tiled roof 495
Tilia sp. 134
Tilia x europaea 143
Tiller
  Dhow 376
  First cars 334-335
  Longboat 380
  Oldsmobile trim 337
  Roman corbita 373
  Sailing dinghy 561
  Steamboat with paddle wheels 391
  Viking ships 374-375
Till and rotation
  Jupiter 44
  Mars 42
  Mercury 34
  The Moon 40
  Neptune 50
  Pluto 51
  Saturn 46
  Uranus 48
  Venus 36
Timber 516
Timber frame
  Ancient Roman building 462, 464-465
  Dome 486
  Medieval building 466-467
  Renaissance building 477
Timber head 380
Timber rafter 492
Timber trellis 603
Time interval signal 330
Timekeeper
  Basketball 532
  Fencing contest 557
  Handball 535
  Judo contest 556
  Lacrosse 541
  Netball 535
  Swimming 558
Time signature 502
Time switch 598
Time-trial bicycle 360
Time zones 618-619
Timing chain 343, 345
Timing chest 343
Timing gear 367
Timpani 503, 504, 505, 518
Timpanum 519
Tin 311
  Mineralization zones 281
  Squash 545
Tinatin Planitia 37
Tinted paper 441
Tip of dodder stem 163
Tip ring 563
Tip section 563

Tire
1906 Renault 336-337
ARV light aircraft 424
Avro triplane 402
BAe-146 jetliner 414
Bicycle 358-359
Blériot XI monoplane 401
BMW R/60 362
Cannondale SH600 hybrid bicycle 361
Curtiss biplane 398
Double-decker tour bus 355
Eddy Merckx racing bicycle 360
First cars 334-335
General use 365
Lockheed Electra airliner 407
MCW Metrobus 333
Metal 324
Motocross racing 368
Motorcycle 365
Pacing sulky 555
Pneumatic 358, 555
Race car 356-357
Renault Clio 352-353
"Rocket" steam locomotive 324
Rossin Italian time-trial bicycle 361
Single-decker bus 333
Slick racing 365
Suzuki RGV500 368-369
Trials 365
Tubeless sports 365
Volkswagen Beetle 340
World War I aircraft 404-405
Tire carrier 357
Tire tread 360, 365, 368
Tire wall 360
Tissue culture 607
Titan 614
Titania 48
Titanium 310
Titanohyrax 74
Toad 182
Toadflax 129
Toaster 598-599
Toe
Albertosaurus 84
Anchisaurus 89
Archacopteryx 85
Bird 188
Caiman 186-187
Corythosaurus 98
Golf club 547
Gorilla 203
Herrerasaurus 86
Human 211, 232-233
Iguanodon 96-97
Lion 194
Lizard 184
Pachycephalosaurus 100
Psittacosaurus 103
Stegoceras 101
Tyrannosaurus 84
Toe clip 360
Toenail
Elephant 200
Gorilla 203
Human 233
Toe piston 514
Toe strap 358-359
Toggle switch 513
Toilet 416, 485
Tolstoj 35
Tomb 458-459, 489
Tomb of Itimad-ud-daula 489
Tomb of King Tjetji 459
Tombolo 294
Tom-toms 518-519
Tondo brush 434
Tone editor control 520
Tonehole 509
Tone pattern selector 520
Tongs 321
Tongue
Allosaurus 85
Caiman 186
Chimpanzee 202
Corythosaurus 98
Cow 198
Dolphin 205
Domestic cat 195
Elephant 200
Human 212, 226, 244, 248
Iguanodon 97
Lamprey 178
Lion 194
Rabbit 196
Rattlesnake 185
Ski boot 552
T'on-wei 376
Tool and battery box 335
Tool/brush-head connector 593
Tool or wand cuff 593
Tools
Rigging 382-383
Sailmaking 384
Viking boatbuilding 374
Tooth
Acanthostega 80
Anchisaurus 89
Ankylosaurus 94
Arsinoitherium 104
Australopithecus 108
Baryonyx 83
Camarasaurus 91
Diplodocus 90
Dragon prowhead 374
Eryops 80
Euoplocephalus 94
Heterodontosaurus 83
Homo habilis 108
Human 108, 246-247, 248
Iguanodon 96
Lambeosaurus 99
Moerithrium 105
Pastels application 440
Phiomia 105
Plateosaurus 88
Protoceratops 102
Smilodon 107
Triceratops 103
Tyrannosaurus 84
Toothless beak
Ankylosaurs 92
Corythosaurus 98
Euoplocephalus 94
Gallimimus 86
Theropods 84
Triceratops 102
Topaz 271
Topcastle 373, 377
Topgallant mast
Battleship 395
Sailing warship 377
Wooden sailing ship 378-379
Top hose 351
Topmast 377, 378
Topping lift 380
Topping-up valve 561
Top-plate 464
Top race 359
Topsail
74-gun ship 379
Double topsail schooner 385
Junk 376
Topset strata 283
Topside strake 393
Top sliding block 437
Tornado GR1A 420-421
Torosaurus 73
Toroweap formation 276
Torpedo 394-397
Torque arm 364, 365
Torquemeter mount 419
Torque tube 338-339
Torque tube assembly 425
Torrential rain 302
Torsional vibration muffler 410-411
Torsion bar 350
Tortillon 440, 441
Tortoise 186
Tortoise skull 77
Torus
Ancient Roman building 463
Asian building 490
Dome 486
Gothic building 470
Medieval building 467-469
Renaissance building 475, 477
Shapes: solid 623
Total solar eclipse 32
Tote board 555
Touch-down 526
Touch-in goal line 530
Touch judge 530
Touch line
Rugby 530
Soccer 524
Touchpad 566
Touchpiece 509
Touchscreen 568-569, 578-579, 587
Touch sensor 609
Tour buses 332
Tour do César 466
Touring bicycle 360, 361
Tourmaline 269
Tower
Ancient Roman building 465
Asian building 490-491
Clock 493
Gothic church 472
Islamic building 488
Medieval building 466-467, 468-469
Modern building 496-497
Nineteenth-century building 492-493
Renaissance building 476
Twentieth-century building 495
Tower Bridge 492-493
Tower vault 469
Towing fairlead 395
Towing hook 335, 426
Town Hall 495
Toxodon 76, 106, 107
TPU connector 571
Trabecula 250-251
Trace fossils 278
Tracery
Gothic building 470-473
Nineteenth-century building 493
Trachea
Bird 189
Brachiosaurus 91
Chimpanzee 202
Dolphin 205
Domestic cat 195
Elephant 200
Gallimimus 86
Human 212, 215, 244-245, 248, 255
Lizard 185
Rabbit 196
Spider 170
Tortoise 187
Trachelion 460
Trachycarpus fortunei 127, 130
Track 413
Track control arm 340
Track events 542, 543
Track gauge 330, 331
Track rod
Elegance and utility 336-337
Ford Model T 338-339
Renault Clio 351
Track shoe 543
Traction motor 328
Trade winds 300
Traffic congestion 332
Traffic surveillance 422
Tragus 242
Trailboard 379
Trailing arm 340
Trailing edge
BAe-146 jetliner components 413, 414, 415
BE 2B tail 405
BE 2B wings 404
Hawker Tempest components 409
Pegasus Quasar ultralight 426-427
Trailing-link arm 414
Trailing wheel 324
Train equipment 330-331
Training gear 396
Trains
Diesel 326-327
Electric 328-329
High-speed 328-329
Steam 324-325
Trams 332-333
Transaxle 340
Transept
Gothic church 470, 473
Medieval church 468-469
Transfer port 342
Transformation 168
Transformer 314, 328
Transform fault 59
Transistor 584
Transitional cell mucosa 257
Transition metals 310, 311
Transit plug 397
Translucent crystal 271
Translucent impasto glaze 443
Translucent white marble 453
Translucent "window" 157
Transmission 350-351
Transmission adaptor plate 344
Transmission electron microscope (TEM) 610, 611
Transmission system 326, 366
Transom
74-gun ship 381
Junk 376
Longboat 380
North wing, Chateau de Monlal 476
Sailing warship 377
Transparency holder 570
Transparent glassy crystal 271
Transparent lower drumhead 518
Transparent tissue 160
Transparent wash 439
Transpiration 136
Transponder aerial 423
Transportation lock 571
Transportation system 332
Transport tissue
Golden barrel cactus 156
Monocotyledons 126
Photosynthesis 138-139
Transversary 377
Transverse arch 485
Baroque church 479
Medieval church 468-469
Transverse colon 249
Transverse dune 283
Transverse foramen 222
Transverse leaf spring 338
Transverse line 535
Transverse process
Human 222-223
Plateosaurus 89
Tyrannosaurus 85
Transverse rib 485
Transverse strut 512
Trapezium 17, 622
Trapezium bone 230
Trapezius muscle 226-227, 229
Trapezoid bone 230
Traps
Butterwort 161
Cobra lily 160
Monkey cup 161
Pitcher plant 115, 160-161
Sundew 160
Venus fly trap 160
Traveler 580
Traveling 553
Travertine shell 464
Tray fascia 595
Tread 477
Tread pattern 365
Treasury of Atreus 461
Treble bridge 514
Treble clef 502
Treble hook 562-563
Treble note strings 515
Treble voice 502
Tree 66-67, 130-131
Energy storage 315
Epiphytes 162-163
Gymnosperms 122-125
Tree fern 112-113
Tree mallow 131
Tree root action 282
Treenail 387
Trefoil
Gothic church 470-473
Nineteenth-century building 493
Trefoil arch 473, 484
Trellis window 459
Trellised river drainage 288
Trembler coil box 335
Trenail 387
Trestle trees 378
Trevithiek, Richard 324
Triac device 600
Trials tire 365
Triangle
Shapes: plane 622
Musical instrument 504, 517
Steamboat with paddle wheels 391
Triangle mosaic 489
Triangular buttress 484
Triangular fossa 242
Triangular horn 85
Triangular lesene 481
Triangular pediment 462
Triangular-section fuselage
Avro triplane 403
Bell-47 helicopter 423
Blackburn monoplane 401
Triangulum 19, 20
Triangulum Australe 21
Triassic period 68-69
Fossil record 279
Geological time 57
Triatic stay 385
Tribune 467-468
Tributary
Coastlines 295
Rivers 288
Tributary moraine 287
Tributary stream 289
Triceps brachii muscle 227
Triceratops 100, 102-103
Trichome 156
Marram grass 113
Triclinic system 270
Tricolpate pollen grain 145
Tricuspid valve 251
Triere 373
Trifid Nebula 16
Trifoliate leaves 128, 130
Laburnum 137
Oxalis sp. 157
Triforium 469
Trigger
Air pistol 549
Biathlon smallbore rifle 549
Cnidocyte structure 167
Trigger hair 160
Trigger mechanism 600
Trigger position 600
Triglyph 460
Trigon 488
Trigonal system 270
Trigone 257
Trigonometry 621
Trike nacelle 426-427
Trilete mark 145
Trilobate rotor 346
Tri-lobed tail 81
Trilobites 64, 78
Earth's evolution 56
Fossil record 279
Trim 352-353
1906 Renault 356-357
Oldsmobile trim 357
Renault Clio 350-351
Volkswagen Beetle 341
Trimala 491
Trimtab 407, 414, 415
Trim tank 416-417
Trinity Chapel, Salisbury Cathedral 470
Tripinnate leaves 137
Triplanes 402-403
Triple bar jump 554
Triple jump 542
Triple spine 130-131
Tripod mast 394
Tripod stand
Congas 519
Drum kit 518
Electronic drums 520
Modeling stand 455
Radial studio easel 437
Tripping palm 386
Tripping ring 372
Triquetral bone 230
Trireme 372-373
Tri-spoke wheel 361, 368, 369
Triton 50
Tri-wring screw 587
Trochanter
Beetle 168
Scorpion 170
Spider 171
Trochlea
Baryonyx 85
Human 241
Trochoid housing 410
Trojan two-stroke engine 342
Trolley 332
Trombone 504, 505, 506, 507
Tropeter 373
Trophoblast 260
Tropic formation 276
Tropic of Cancer
Satellite map 265
Surface currents 297
Tropic of Capricorn
Satellite map 265
Surface currents 297
Tropical cyclone 302
Tropical orchids 162

Tropical rainforest 39, 66
Troposphere
  Earth's atmosphere 300
  Jupiter's atmosphere 45
  Mars' atmosphere 43
  Saturn's atmosphere 47
  Venus' atmosphere 37
Trout 180
Trout angling 562
Truck
  Early tram 332
  Greek galley 372
  Longboat 380
  Wooden sailing ship 378-379
Trumpet 504, 506, 503
Truncate leaf base 137
Trunk
  Elephant 200-201
  Mammoth 107
  Phiomia 105
  Tree fern 112
  Woody flowering plant 130-131
Trunnion 395
Truss
  Gothic church 473
  Modern building 497-499
  Steam boat with paddle wheels 391
Truss rod 513
Try 530, 531
T-section beam 492
Tsiolkovsky 41
T-type cantilevered fin 426
Tu-144 416
Tuba 504, 505
Tube fret 174, 175
Tubeless sports tire 365
Tuber
  Broomrape 145
  Dryland plants 157
  Horsetail 120
  Potato 128
  Vegetative reproduction 155
Tubercle
  Corythosaurus 98
  Golden barrel cactus 156
  Sea urchins 174
  Starfish 174
  Stem projections 156
Tubular bells 504, 516
Tubular chassis 335
Tubular drums 518
Tubular open cradle frame 369
Tubular petioles 160
Tuck 381
Tudor arch 484
Tufted duck 188
Tug propeller 391
Tulip mount 563
Tuner/amplifier link cables 585
Tuner sellings memory microchip 585
Tungsten
  Mineralization zones 281
  Periodic table 310
Tungsten carbide lip 450
Tungsten filament 319
Tunica adventitia 252
Tunica intima 252
Tunica media 252
Tuning adjustor 510-511
Tuning pedal 519
Tuning peg 510, 511
Tuning pin 514, 515
Tuning slide 506
Tunnel
  Cave 285
  Trains 350
Tunnel vault 485
Tuojiangosaurus 92
Tupelo 137
Turbine
  Energy 314-315
  Floodgate 604
  Jet engines 418-419

Nuclear "Hunter-Killer" submarine 397
Turbo-charged diesel engine 327
Turbocharger 356
Turbofan engine 418-419
  Landing gear 412
Turbo impeller 347
Turbojet engine 418-419
  Landing gear 412
  Supersonic jetliner 416
Turbo propeller 347
Turboprop engine 418-419
Turdus viscivorus 190
Turfed roof 602, 603
Turgai strait 71
Turkish crescent finial 488
Turk's head 383
Turnbuckle
  Avro triplane 402
  Blackburn monoplane 401
  Curtiss biplane 398
  LVG CVI fighter 405
  Rigging screw 383
Turn indicator 558
Turning force 320
Turning indicator 332, 333
Turning judge 558
Turning vane 357
Turns 555
Turntable 596
Turntable rotator 596
Turpentine 436
Turret 486
  Baroque church 481
  Battleship 394-395
  Gothic church 470-471
  Gun turret 396
  Medieval building 466, 468
  Nineteenth-century building 493
  Renaissance building 476-477
Turtle 72-73, 186-187
Tuscan capital 465
Tuscan pilaster 465, 483
Tusche 446
Tusche pen 448
Tusche stick 448
Tusk
  Elephant 200-201
  Mammoth 107
  Phiomia 105
TV mini-camera 356
TV power button 585
Tweeter loudspeaker connectors 585
Twelfth century
  Building 466-467
  Church 469, 473
  Roof 490
  Style 468, 470
Twentieth-century buildings 494-495
Twin-blade main rotor 423
Twin carbon-fiber disc brake 369
Twin carburetors 427
Twin-cylinder engine
  Harley-Davidson 362
  Pegasus Quasar ultralight 427
  Steam-powered Cugnot 334
Twin-domed forehead 200
Twine 384
Twin-lobed leaf blade 160
Twin nose-wheel 420
Twin rate spring 365
Twin rear axle 333
Twin rudder 372
Twin-wheel main landing gear 414
Twin-wheel nose-gear 417, 420
Twist 388
Twist dive 558, 559
Twisted wire habit 271
Two-lobed stigma 142
Two-pulley system 320
Two-seater cockpit 421
Two-stroke combustion engine 366
Two-toed ungulates 198
Two-towered gate 467
Tyagaraja 35
Tycho 40
Tye 377
Tye halyard 374
Tympan 449
Tympanic bullet 194
Tympanic canal 243
Tympanic membrane 243
Tympanum
  Frog 182
  Quail chick 193
Typhoon 302
Tyrannosaurus 73, 84-85
Tyringham House 483

U

UHF aerial 420
UK loading gauges 331
Ulmus minor 144
Ulna
  Archaeopteryx 85
  Arsinoitherium 104
  Baryonyx 85
  Bird 189, 191
  Brachiosaurus 91
  Crocodile 186
  Diplodocus 90
  Domestic cat 195
  Elephant 90, 201
  Eryops 80
  Euoplocephalus 94
  Gallimimus 86
  Hare 197
  Horse 199
  Human 218, 230
  Iguanodon 96
  Kangaroo 206
  Kentrosaurus 93
  Lizard 184
  Parasaurolophus 99
  Pareiasaur 81
  Plateosaurus 88
  Platypus 206
  Rhesus monkey 202
  Seal 204
  Stegoceras 100, 101
  Stegosaurus 93
  Struthiomimus 87
  Toxodon 106
  Triceratops 102
  Tuojiangosaurus 93
  Turtle 187
  Tyrannosaurus 84
Ulnar artery 231, 253
Ulnar nerve 231, 238
Ultra-high frequency (UHF) antenna 615
Ultralights 410, 426-427
Ultramarine lapis lazuli 433
Ultrasound scan 214
Ultraviolet light 145, 319
Ultraviolet radiation 22, 319
Ultraviolet solar radiation 300
Umbels 143
Umbilical artery and vein 260
Umbilical cord 260-261
Umbilicus 211, 260
Umbo 176
Umbra 32
Umbrella 491
Umbriel 48
UMD drive ribbon cable 379
Umpire
  Badminton 545
  Baseball 536
  Cricket 538
  Football 526
  Hockey 540
  Lacrosse 541
  Netball 535
  Tennis 544
  Volleyball 534
Umpire signals 537
Una corda pedal 514, 515
Unarmed combat 556
Underarm pass 535
Underframe 332
Underground mycelium 115
Underground stem 154
Underground storage organs 154-155
Underground stream 284-285
Underground water
  Lake formation 292
  Rivers 288
Underhand serve 534
Under plastron 557
Under-turntable roller ring 596
Underwater digital camera 581
Underwater mountains 298
Underwing fairing 425
Unenergized electrode 584
Ungulates 198-199
Unicellular organisms 56
Unified leaf pair 157
Uniform motion 321
"Union Pacific" diesel train 326
Unipolar neuron 239
Unison 503
Unit number 328
Units of measurement 620
Universal resource locator (URL) address 577
Universal serial bus (USB) ports 566, 567, 570
Universal serial bus (USB) programmer 591
Universal veil 114-115
Universe 10-11
Unmapped region
  Degas and Brönte 34
  Structure of Mercury 35
Unnilennium 311
Unnilhexium 310
Unniloctium 311
Unnilpentium 310
Unnilquandium 310
Unnilseptium 310
Unreactive gas mixture 319
Unreactive metals 311
Unstable elements 310
Unukalhai 21
Upcurved edge 191
Upfold 60
Upfold trap 280
Upholstery 336-337
Upholstery brush 593
Uplifted block fault mountain 62
Upper arm 210
Upper Belvedere 482
Upper Carboniferous Coal Measures 61
Upper Carboniferous Millstone Grit 60-61
Upper crankcase 410
Upper crux of antihelix 242
Upper deadeye 382-383
Upper deck 380
Upper deck passenger door 573
Upper deck windows 572
Upper epidermis 159
Upper eyelid 213
Upper fin 423
Upper finishing 381
Upper Frater 473
Upper gallery 379
Upper head 387
Upper jaw 212, 220-221, 244-245, 246, 248
Upper jaw tusk 105
Upper joint
  Clarinet 508
  Cor Anglais 508
  Oboe 508
Upper lobe of lung 215, 254-255
Upper octave key 509
Upper rudder 416-417
Upper seed axis 152-153
Upper sheer strake 393
Upper topsail 385
Upper wireless and telegraphy yard 395
Upright man 108
Upright piano 514
Upright planks jump 554
Upright poles jump 554
Upsilon Sagittarii 21
Upstream gates 560
Upthrow 60
Urachus 257
Ural mountains
  Cretaceous period 73
  Earth's physical features 265
  Jurassic period 71
  Late Carboniferous period 67
  Triassic period 69
Uranium 310
Uranium fuel 314
Uranius Tholus 43
Uranus 48-49
  Solar system 31
Ureter
  Bird 189
  Bony fish 181
  Domestic cat 195
  Elephant 200
  Frog 182
  Human 215, 256-259
  Lizard 185
  Rabbit 196
  Snail 177
Ureteric orifice 257
Urethra
  Chimpanzee 202
  Domestic cat 195
  Human 256-257, 259, 261
  Rabbit 196
Urethral opening 259
Urethral sphincter muscle 257
Urinary bladder 181
Urinary system 256-257
Urinogenital opening
  Bony fish 181
  Dolphin 205
URL 577
Urn 478, 481, 487
Urodela 182
Uropod 172
Urostyle 183
Ursa Major 18, 19
Ursa Minor 18, 21
Ursus americanus 195
Ursus spelaeus 77, 106
U-shaped gouge 449
USB *see* Universal serial bus (USB)
USB ports 566
USB port 566, 586
USB programmer assembly 591
User name 576
U-shaped valley 286-287
Uterine wall 260-261
Uterus
  Chimpanzee 202
  Elephant 200
  Human 258-259
Utricle 243
U-tube 313
Utzon, J. 499
Uvula 212, 245, 248

V

V1 "flying bomb" 408
V12 cylinder arrangement 345
V4 engine unit
  British Rail Class 20 diesel 327
  Honda VF750 364
Vacuole
  Chlamydomonas sp. 116
  Diatom 116
  Human cell 216
  Palisade mesophyll 139
Vacuum brake lever 325
Vacuum circuit braker 328
Vacuum cleaner 592-593
Vacuum operated inlet valve 362
Vacuum pump cabinet 611
Vacuum reservoir 324
Vacuum valve 610
Vagina
  Chimpanzee 202
  Elephant 200
  Human 258-259, 261
  Snail 177
  Spider 170
Valance
  1906 Renault 337
  Ford Model T 339
  Volkswagen Beetle 341
Valency electrons 310
Vallate papillae 244
Vallecular canal 120
Valles Marineris 43
Valley
  Coastline 294
  Glacier 286-287
  Grand Canyon 277
  Mountain 62
  River features 290
  River 288-289
  Rock cycle stages 267
Valley floor erosion 267
Valley head 289
Valley rafter 473
Valley spring 292
Vālmiki 35
Valve 359
Valve chest 324
Valve cusp 252
Valve lifter 367
Valve return spring 347
Valve rocker 344, 402
Valves
  Bivalves 176
  Dehiscent fruit 151
  Indehiscent fruit 150
  Scallop 176
Valve slide 506, 507
Valve spring 343, 344
Valve system 506
Vanadium 310
Van Allen radiation belt 38
Van de Graaff 41
Van de Graaff generator 316
Vane 191
Van Eyck 35
Vang 378
Vanishing point 431

Vapor barrier 603
Variable incidence air intake 420
Variable incidence gust-alleviator 421
Variable nozzle 416-417
Variable pitch aluminum-alloy blade 408
Variable pitch propeller 396
Variable time control knob 598-599
Variegated lamina 131, 137
Varnish 348, 436
Vasa recta 256
Vascular cambium 134-135
Vascular plants 279
Vascular plexus 235
Vascular strand 149
Vascular system 162-163
Vascular tissue 130
  Aerial shoot 155
  Apical meristem 134
  Bishop pine 124
  Canadian pond weed 159
  Clubmoss stem 120
  Corm 155
  Dicotyledon 127
  Dodder 163
  Epiphytic orchid 162
  Fern rachis 121
  Higher plants 118-119
  Horsetail stem 120
  Marram grass 113
  Monocotyledon 126-127
  Parasite host 163
  Perennials 130-131
  Pine needle 124
  Pine root/stem 125
  Radicle 152
  Rhizome 155
  Root 132-133
  Stem 134-135
  Water hyacinth root 158
  Water lily leaf 159
  Woody plants 130-131
Vas deferens
  Domestic cat 195
  Human 259
  Rabbit 196
Vastitas Borealis 43
Vastus lateralis muscle 225-226
Vastus medialis muscle 225-226
Vault 484-485, 496
  Ancient Roman building 462-464
  Baroque church 479
  Gothic building 470
  Medieval building 467-469
  Modern building 496, 499
  Nineteenth-century building 492-493
  Renaissance building 477
Vaulting shaft 468-469
V-belt pulley 347
VCR connections 585
Vedette boat 395
Vega 19, 20
  Our galaxy and nearby galaxies 15
Vegetable oil 436
Vegetative reproduction 154-155
Veil 114-115
Vein
  Alveolar 247
  Anterior median 253
  Axillary 253
  Basilic 253
  Brachiocephalic 253
  Bronchial 254
  Cardiac 250
  Central retinal 240
  Cephalic 176, 253
  Common iliac 215, 253, 257

Dicotyledon leaf 126-127
  Digital 253
  External iliac 215, 253
  Femoral 253
  Gastroepiploic 253
  Great saphenous 253
  Hepatic portal 253
  Hogweed leaf 129
  Inferior mesenteric 253
  Inferior vena cava 215, 252-253, 257
  Insect 168, 169
  Interlobular 256
  Internal iliac 253
  Internal jugular 253
  Jugular 215
  Leaf 136, 138-139
  Median cubital 253
  Monocotyledon leaf 126
  Palmar 253
  Portal 252
  Pulmonary 251, 253, 254
  Pulp 247
  Renal 256-257
  Short saphenous 253
  Subclavian 253
  Superior mesenteric 253
  Superior vena cava 215, 251, 252-253, 255
  Suprarenal 257
  Testicular 257
  Tree mallow leaf 131
  Umbilical 260
  Water hyacinth leaf 158
  Water lily leaf 159
Vela 18, 21
Velamen 162
Velarium 464
Velar scale 115
Vela Supernova Remnant 17
Vellum 432
Velocette overhead valve (OHV) engine 367
Velum 373
Vena cava
  Frog 182
  Inferior 215, 252-253, 257
  Superior 215, 251, 252-253, 255
Vendelinus 40
Veneer 462
Venomous snake 184
Vent
  Frigate 397
  Igneous rock structures 275
  Mountain building 62
  Rock cycle 266
  Suzuki RGV500 368
  Volcano 272-273
Ventilation 462
Ventilator 422, 425
Ventilator exit 406-407
Ventral abdominal artery 173
Ventral antebrachial muscle 94
Ventral aorta 179
Ventral fin 179
Ventral margin of shell 176
Ventral nerve cord 169, 173
Ventral scale 184, 186
Ventricle
  Brain 236-237
  Heart 215, 250-251, 252
Ventricular diastole 251
Ventricular systole 251
Venturi 424
Venus 36-37
  Solar system 30
Venus fly trap 160
Verdaccio 433
Verge 464, 492
Vermiculated rustication 482
Vermilion 433
Vermilion border of lip 213
Vermilion Cliffs 277
Versal lettering 445
Vertebra 261
  Bony fish 180
  Cervical 212, 222
  Frog 183
  Lumbar 222-223
  Rattlesnake 185
  Rudimentary 260
  Thoracic 222-223
  Turtle 187
  Westlothiana 81
Vertebral artery 223, 252
Vertebral body 223
Vertebral column 218, 222, 257
Vertebral foramen 222-223
Vertebral shield 187
Vertebrates 56, 64, 104
  Fossil record 279
Vertex
  Building 495
  Human body 212
Vertical air current 302
Vertical batten 602
Vertical cleavage 270
Vertical frame ladder 392
Vertical movement
  Faults and folds 60
  Lake formation 292
Vertical muffler 329
Vertical pupil 186
Vertical ridge 129
Vertical spindle 387
Vertical stroke 445
Vertical tailplane 572
Very high frequency (VHF) radio 318
Vesicle 148
Vespa Grand Sport 160
  Mark 1 363
Vespa scooter 362, 363
Vessel
  Baroque church 479
  Gothic church 470
  Medieval church 468-469
Vesta Rupes 37
Vestas A47 wind turbine 604
Vestibular canal 243
Vestibular membrane 243
Vestibular nerve 243
Vestibule
  Ancient Greek temple 461
  Baroque church 481
  Human body 212, 245
  Medieval church 469
  Neoclassical building 483
Vestibulocochlear nerve 243
VHF aerial
  B-17 bomber 408-409
  BAe-146 jetliner 415
  Bell Jetranger helicopter 423
  Concorde 416-417
  VHF radio 318
VHF omni-range aerial
  Bell-47 helicopter 422
  Concorde, the 417
VHF omni-range and instrument-landing-system aerial 412
Vibraphone 504, 516, 517
Vibration-reducing fan mounting 597
Vibration-reducing muffler foot 58
Vibrations
  Brass instruments 506
  Stringed instruments 510
Vibrato arm 513
Vibrato effect 516, 517
Vibrissa
  Lion 194
  Rabbit 196
  Rat 196
  Seal 204
Vicia faba 133, 152
Video
  Digital 582-583
  Streamed internet 577
Video camera 610
Video input/output circuit board 585
Viewfinder 582
Viewing screen 610
Viewing window 581
Viewing window objective lens aperture 580
Viking ships 374-375
Villa Rotunda 475
Villa Savoye 494
Villi of mucosa 248
Viola 503, 504, 505, 510, 511
Violent eruptions 272
Violet light 318
Violin 503, 504, 505, 510
Violoncello 510-511
Virginia opossum 207
Virgo 18, 21
Virtual mixing board 521
Visceral cartilage 254
Visceral hump 177
Visceral pericardium 250
Viscous coupling 344-345
Visible and infrared spectrometers 614
Visible light 318-319
Vision 237
Visor 416-417
Visual recognition 237
Vitreous glass mosaic 451
Vitreous glass tessera 450, 451
Vitreous humor 240
Vitta 151
Vivaldi 35
Vocal cords 245
Voices 503
Volans 21
Volcanic activity
  Mineralization zones 280
  Rock cycle 266
Volcanic eruption 26
Volcanic gases 64
Volcanic island 58, 299
Volcanic lake 293
Volcanic lava
  Jupiter 44
  Mars 42
  The Moon 40
  Venus 36
Volcanic mountain 62
Volcanic rock 298, 306
Volcano 58, 63, 272-273
  Jupiter 44
  Locations 273
  Mars 42
  Mineralization zones 281
  Mountain building 62-63
  Ocean floor 298
  Vent 62
  Venus 36
Volkmann's canal 247
Volkmann's vessel 225
Volkswagen Beetle 340-341
Volleyball 534-535
Voltage 306, 316
Voltage circuitry 597
Voltage reduction and regulation circuits 585
Voltage regulators 596
Voltage stabilizer 597
Voltage transformers 596
Volume 306, 307
Volume control
  Electronic instruments 520, 521
  Streamed internet radio 577
  Home cinema 585
  Nintendo Wii Fit Plus 579
  Personal music 586-587
Volumes 623
Volume slider 577
Volute
  Ancient Greek building 460-461
  Baroque church 479, 481
  Dome 486
  Islamic building 488
  Neoclassical building 478, 480
  Renaissance building 476-477
Volva 114-115
Volvox sp. 116
Vomer 221
Von Kármàn 41
Voussoir 484-485
  Ancient Roman building 465
  Neoclassical building 482
  Renaissance building 474
V-shaped gouge 449
V-shaped valley
  River features 290
  Rivers 288-289
V-strut 404-405
VTEC engine 354
V-twin engine 362, 363
Vulpecula 19
Vulture 190
Vulva 200
Vyāsa 35
Vyne 482

W

Wadi 283
Wagner 35
Wagon 324
Wagon bogie 330
Wagon vault 485
Wahweap sandstone 276
Waist
  74-gun ship 380-381
  Human 210
  Stringed instruments 510-511
Waistband 548
Waist gun 408
Wale
  74-gun ship 381
  Roman corbita 373
  Sailing warship 376-377
Walkway 497
Wall
  Ancient Greek temple 461
  Ancient Roman building 462, 465
  Baroque building 478-479, 481
  Carpel 148, 151
  Cell 112, 117, 132, 139
  Concrete 496
  Fruit 148-151
  Fungal tissue 115
  Glass 496
  Gothic church 470
  Islamic building 488
  Medieval building 466-467, 469
  Modern building 498-499
  Neoclassical building 479, 482
  Nineteenth-century mill 492
  Ovary 140, 150
  Renaissance building 476-477
  Twentieth-century building 494
Wall anchor 407
Wall construction 602
Wall panel 406-407
Wall painting 434
Walrus 204
Walter 40
Wand 592, 593
Wand handle and brushbar controls 592
Wand/handle connector 593
Wand telescopic link 593
Wankel, Felix 346
Wankel rotary engine 346-347
Wannanosaurus 101
Wardrobe 416
Wardroom 381
Warhead 394
Warm air 300, 302-303
Warm blood
  Mammals 104
  Theropods 84
Warm electronics box 615
Warm front 302-303
Warm occlusion 302
Warm periods 56
Warning horn 327, 329
Warning light 328, 356
Warship
  74-gun ship 379, 380-381
  Battleship 394-395
  Frigate 396-397
  Ironclad 392-393
  Man-of-war 378-379,
  Sailing warship 376-377
  Submarine 396-397
Wasatch formation 276
Washable pre-motor filter 592
Wash cant 378
Washer-dryer 594-595
Wash over dry brush 439
Washburn 12-string guitar 513
Washer
  Bicycle 358
  Power drill 600-601
  Toaster 598-599
Washer jet 353
Washes 438, 439
Washing machine 315
Wasp 168
Waste heat 314-315
Waste water anti-siphon pipe hook 595
Waste water pipe 595
Water 38, 66
  Absorption 150
  Amphibian 80
  Changing states 307
  "Deltic" diesel-electric locomotive 326
  Energy generation 314-315
  Epiphyte supply 162
  Fermentation 313
  Lithographic printing 446
  Mars 42

Molecule 138
Oceans and seas 296
Photosynthesis 138
Pollination 144
Reversible reactions 312
Seed germination 152-155
Solutions 306
Storage organs 156-157
Transport 134, 139
Water and oil pump assembly 356
Waterborne sports 560-561
Water-closet 483
Watercolor 438-439
Watercolor paint pan 438
Watercolor paper 439, 441
Watercolor-style acrylic painting 442, 443
Water connection 342
Water-cooled engine 366
Water cycle 288
Water density 296
Water distribution 264
Water droplets 45
Waterfall 291
Glacier 286
River 289-290
Rock cycle 267
Water fern 158
Water float 324
Water hardness adjustment and filter flap lever 595
Water hyacinth 158
Water ice
Jupiter's atmosphere 45
Mercury's atmosphere 47
Structure of comet 53
Structure of Mars 43
Structure of Neptune 51
Water-ice fog 42
Water-ice permafrost 43
Water inlet connector 595
Water inlet hose 595
Water inlet pipe 595
Water inlet valves 595
Water jacket
Daimler engine 343
Ford diesel engine 347
Humber engine 343
Jaguar straight six engine 344
Water key 506, 507
Watcr lily 158-159
Waterline 380
Water obstacle 546
Water outlet 425
Water passage 346
Water pipe
1906 Renault 337
Humber engine 343
Wright Flyer 399
Water pressurizer 314
Waterproof acrylic paint 442
Waterproof cable connector 605
Waterproof covering
Bishop pine needles 124
Golden barrel cactus 156
Haworthia truncata 157
Lithops bromfieldii 157
Monocotyledon leaf 126
Rush stem 135
Wetland plants 158
Waterproof shell 80
Waterproof ski clothing 553
Waterproof skin 81
Waterproof stowage box 427
Water pump
Hybrid car 354
Jaguar V12 engine 345
Renault Clio 351
White Steam Car 342
Water pump pulley 347
Water rail 345
Water reactor 314
Water-retaining cuticle 78
Water salinity 296
Water-saturated permeable rock
Lakes and groundwater 292
Mineral resources 280-281
Watershed 289
Water shoot 560
Water softener dial 595
Water-soluble glue 450
Water storage tank 497
Water-storing parenchyma 156-157
Water supply
Gun turret 396
Steam locomotive 324
Water table
Cave system 284
Lake formation 292
Water tank
Bordino Steam Carriage 334
"Ellerman Lines" steam locomotive 324
Steam iron 594
While Steam Car 342
Water vapor
Chemical reactions 312-313
Hurricane structure 303
Jupiter's atmosphere 45
Mars' atmosphere 43
Saturn's atmosphere 47
Venus' atmosphere 37
Water cycle 288
Water vascular system 174
Waterway 380, 393
Wattle-and-daub
Ancient Roman building 462, 464-465
Medieval house 466
Wave 294, 298
Erosion 294
Features 294
Properties 318
Wave-cut platform 295
Waveguide 596, 597
Wavelength 318
Wavellite 269
Wavering pitch 516, 517
Wavy foliation 267
Wax modeling 452
Wax riser 454
Wax runner 454
Waxy cuticle 156, 157
Waxy fruit skin 149
Waxy laminae 159
Waxy zone 161
Weapon-bay bulkhead 421
Weaponry 375
Weasel 194
Weather 302-303
Weathercock 486
Weathering 282-283
Gothic church 471-472
Medieval church 469
Mineral deposits 280
Renaissance building 477
Rock cycle 266
Sedimentary rocks 276
Weather radar 416
Weather shutter for gun 394
Weather-vane 471, 477
Web
Frog 182
Internet 576
Webbed feet 188, 190
Web browser 577
Web pages 577
Webcam 566
Website address 577
Weight
Arch 484
All-round bicycle 360
Bolts 548
Measurement 320, 590
Motorcycle engine 366
Newton meters 320
Weights 562
Wei-wei 376
Welding tool 608
Weld line 392
Welt 122-123
Welwitschia mirabilis 122-123
Werner motorcycle 362
Weslake Speedway motorcycle 369
West Africa 73
West Australian current 297
Westerlies 300
Westlothiana 67, 80-81
Westminster Abbey 484
Westminster Cathedral 493
Wet-in-wet wash 438, 439
Wetland plants 158-159
Wet season 295
Wet wash 438
Wezen 18
Canis Major 21
Whaler 395
Whales 204-205
Wheat 109, 150
Wheel
1906 Renault 337
Alloy 356, 357
Bicycle 358-359
Diesel motor output 326
First cars 354-355
Force/motion 320
Ford Model T 338-339
Harley-Davidson FLHS
Electra Glide 363
Mars exploration rover (MER) 615
Mazda RX-7 346
Motorcycle 364
Pacing sulky 555
Paddle 390-391
Renault Clio 350-351
Rossin Italian time-trial bicycle 361
Ship 378, 390, 394
Single scull 561
Volkswagen Beetle 340
Weslake Speedway motorcycle 369
Wheel axle
BAe-146 jetliner 414
Touring bicycle 360
Wheelbase 360
Wheelchair access 333
Wheel fairing
Blackburn monoplane 400
Pegasus Quasar ultralight 427
Pegasus XL SE ultralight 426
Wheel fork 335
Wheel guard 324, 369, 593
Wheel hub 414
Wheel nut 356, 357
Wheel sets 327, 329
Wheel sparer 561
Whelp 587
Whetstone 452
Whip 555
Whipping 384, 388
Whisker
Lion 194
Rabbit 196
Rat 196
Seal 204
Whisker boom 382
"Whispering Gallery" 484
Whistle
Iron paddlesteamer 392
Life jacket 561
Referee 524
Whistle lever 325
White belt 556
White blood cells 217, 253
White Cliffs 276
White diamond 268
White dwarfs
Small stars 24-25
Stars 22-23
White feldspar 275
White-gray crystal 271
White light 318
White matter
Cerebrum 236-237
Spinal cord 238
White of eye 213
White oval
Jupiter 44-45
Saturn 46
White spirit 436
White Steam Car 542
White stork 188
White warning light 528
White whale 204
Whorls
Flower 140
Green alga cell 116
Sepals 144, 149
Wicket 538
Wicket-keeper 538
Wide-angle camera 614
Widened joint 282
Wide receiver 526
Wide-screen plasma display 584
Wiener 41
Wi-fi antenna 569, 579
Wi-fi board 579
Wii balance board 579
Wii hand controller 579
Willow grouse 193
Wind
Atmosphere 300
Ekman spiral 297
Energy generation 314
Oceans and seas 296-297
Rock cycle 266-267
Water cycle 288
Weather 302
Weathering and erosion 282-283
Windspeed 303
Windcheetah SL Mark VI "Speedy" racing HPV bicycle 561
Wind chest 514
Wind controller 521
Wind deflector 341
Wind-dispersed seeds 150-151
Wind erosion 282-283
Coastline 294
Winding cornice 472
Wind instruments 508, 509
Brass 506, 507
Electronic 520
Woodwind 508, 509
Windlass
Buildings 467, 477
Roman corbita 372
Windlass bar 380
Window
Ancient Egyptian building 459
Ancient Roman building 463, 465
Asian building 490-491
Baroque church 479-481
Dome 486-487
Dormer 495
Double-decker tour bus 333
"Eurostar" multi-voltage electric train 329
Gothic building 470-475
MCW Metrobus 333
Medieval building 466-469
Modern building 498, 499
Neoclassical building 478, 482-483
Nineteenth-century building 492-493
Renaissance building 474, 476
Rococo style 482
Single-decker bus 333
TGV electric high-speed train 329
Twentieth-century building 494-495
Window blind 336, 572
Window controls 576, 577
Window-frame 486
Window glass 348
Window jamb 479, 482, 483
Windowsill
Baroque church 479
Neoclassical building 482-485
Twentieth-century building 494
Window shade button 577
Window stage 477
Wind-pollinated plants 144
Windshield
Airbus 380 573
BAe-146 jetliner components 412
BE 2B bomber 404
BMW R/60 sidecar 362
Concorde, the 416-417
"Deltic" diesel-electric locomotive 327
Double-decker tour bus 333
Ford Model T 339
Harley-Davidson FLHS
Honda Insight 354
Electra Glide 563
Hawker Tempest components 409
Kirby BSA racing sidecar 362
Lockheed Electra airliner 406-407
Tornado 420
Windshield wiper
"Deltic" diesel-electric locomotive 327
"Eurostar" multi-voltage electric train 329
Italian State Railroads Class 402 328
MCW Metrobus 332
Paris Metro 328
TGV electric high-speed train 329
"Union Pacific" locomotive 326
Volkswagen Beetle 341
Windsor green 438
Windspeed 303
Wind synthesizer 521
Wind turbine 604, 605
Wind-up 537
Windvane 375, 605
Windward face 283
Wing
1906 Renault 336
Alula 191
ARV light aircraft 424-425
Australian rules football 528
Avro biplane 403
BAe-146 jetliner components 413, 414
BE 2B wings 404
Beetle 168
Biplanes and triplanes 402
Bird 188, 191
Blackburn monoplane 401
Bones 191
Bumblebee 168
Butterfly 169
Cobra lily 160
Coverts 188
Curtiss biplane 398
Deer hopper dry fly 563
Developing 192
Dry fruit 150-151
Early monoplanes 400
Fealher 188, 191
Ford Model T 338
Formula One race car 357
Gliders, hang-gliders, and ultralights 426
Handball 535
Hawker Tempest components 409
Hockey 540
Ice hockey 550
Lockheed Electra airliner 406
Pine seed 122
Pitcher plant 113
Rugby 530
Scots pine seed 122
Showjumping fence 554
Ski boot safety binding 552
Spurious 191
Sycamore 131
Wing assembly 413
Wing attack 535, 541
Wing case 168
Wing defense
Lacrosse 541
Netball 535
Winged seeds
Scots pine 122
Sycamore 131, 151
Winged stem 129
Wing end-plate 357
Wing-feather impression 85
Wing fillet panel 409
Wingframe 427
Wing landing gear 572, 573
Wing leading edge 573
Winglet 356
Wing mirror 354
Wing piping 341
Wing-protecting skid 398-399
Wing-root glove fairing 420-421
Wing-root mount 413
Wing scar 122
Wing stay 339
Wing strut
ARV light aircraft 424-425
Avro triplane 402-403
Curtiss biplane 398
Wing supports 357
Wingtip
ARV light aircraft 424
BE 2B wings 404
Hawker Tempest components 409
Schleicher glider 426
Wingtip aerial fairing 421
Wing vein 168, 169
Wing warping 400
Wire armature 454, 455
Wire bristle brush 519
Wire coil 605

Wire-ended cutting tool 454
Wire-end tools 452
Wire gauze pad 342
Wireless and telegraphy yard 395
Wireless office 397
Wires 518
Wire wheel 402
Wiring loom 596
Wishbone
  Bird 189
  Formula One race car 357
Withdrawal stride 543
Withdrawing-room 483
Withers 199
Wolf 195
Wolffian duct 179
Wolf hair brush 444
Wollastonite 271
Womb 258-259
Women's lacrosse field 540, 541
Women's shot 542
Wood
  Golf club 547
  Sculpture 454
Wood block 446, 449
Wood capstan 387
Woodcarving 452, 453
Woodcut 446
Wooden arrow 109
Wooden artillery wheel 337
Wooden bar 516
Wooden boarding 602
Wooden body 510
Wooden body-shell 519
Wooden buffer 324
Wooden case 514, 515
Wooden-domed deck 403
Wooden driving wheel 324
Wooden frame
  Harp 511
  Printing mesh 446, 448
  Sculpture 452
  Steam-powered Cugnot "Fardier" 334
Wooden golf clubs 546, 547
Wood engraving 446, 447
Wood engraving print 449
Wooden grip 549
Wooden hearth 109
Wooden "key" 331
Wooden packing 397
Wooden panel 473
Wooden sailing ship 378-379
Wooden sleeper 324, 331
Wooden spoke 334
Wooden-spoked wheel 339
Wooden stands 554
Wooden wheel 334
Woodwind instruments 504, 505, 508, 509
Woodwork 467
Woody flowering plants 126, 130–131
Woody pericarps 150
Woody plants 126
Woody scales
  Bishop pine cone 124
  Smooth cypress 123
Woody stem 134-135
Woofer loudspeaker connector 585
Woolding 376
Work 314
Working chamber 396
World War I aircraft 404-405
World War II aircraft 408-409
World Wide Web 576
Worming 388
Worms
  Earth's evolution 56
  Fossil record 279
Woven dacron 384
Wrack 116-117
Wren, C. 478
  Baroque church 480
  Cathedral dome 484, 487
Wrest plank
  Concert grand piano 515
  Upright piano 514
Wright brothers
  Modern piston aero-engines 410
  Pioneers of flighl 398-399
Wright, F. L. 495
Wright Flyer 398-399
Wrist
  Corythosaurus 98
  Elephant 90
  Human 211, 230-231
  Iguanodon 97
  Stegosaurus 92
  Triceratops 102
Wrist joint
  Baryonyx 85
  Brachiosaurus 91
  Diplodocus 90
  Euoplocephalus 94
  Human 218
  Parasaurolophus 99
  Plateosaurus 88
  Robot 608
  Stegoceras 100, 101
  Tyrannosaurus 84
Wrist pin 390
Wrist position 444
Writing tools 444
Wrought iron boiler 324
Wrought iron rail 324
Wuerhosaurus 93
Wulfenite 269

X

Xerophytes 156-157
Xi2 Sagittarii 21
Xi Orionis 18
Xi Pegasi 19
X line 445
X-ray 318-319
  Colon 214
  Gallbladder 214
  Hand 230
X-ray emission 28
X-ray image of Crab Nebula 28
"X" turret 395
Xylem
  Bishop pine 124
  Clubmoss stem 120
  Dicotyledons 126-127
  Dodder host 163
  Epiphytic orchid 162
  Fern rachis 121
  Higher plants 118-119
  Horsetail stem 120
  Marram grass 113
  Monocotyledons 126-127
  Pine needle 124
  Pine root/stem 125
  Radicle 152
  Root 132
  Stem 134-135
  Water hyacinth root 158
  Water lily leaf 159
Xylem fibers 134-135

Y

Yacht racing 560
Yangchuanosaurus 85
Yangtze River 265
Yard 382
  Battleship 395
  Double topsail schooner 385
  Greek and Roman ships 372, 373
  Steel 392
  Tea clipper 392
  Viking karv 375
Yardang 282
Yardarm 379
Yardsman 526
Yasti 490, 491
Yaw control 605
Yaw ring 605
Year
  Earth 30
  Jupiter 30
  Mars 30
  Mercury 26, 34
  Neptune 31
  Planets 30-31
  Pluto 31
  Saturn 31
  Uranus 31
  Venus 30
Yeast
  Fermentation 313
  Fungi 114
Yellow card 524
Yellow light 318, 331
Yellow ocher 442
Yellow orpiment 271
Yellow River 265
Yellow warning arm 330
Yellow-wort 144
Yew 123
Y.M.C.A. 532
Yolk 192
Yolk sac 192
Ytterbium 311
Yttrium 310
"Y" turret 395
Yucca 126
Yucca sp. 126

Z

Zagros Mountains 75
Zaire 265
Zap button 586
Zea mays 127
Zeami 35
Zebra 198
Zeeman 41
Zeilleria frenzlii 66
Zeppelin ipod speaker dock 586
Zeta Centauri 21
Zeta Sagittarii 21
Zeugen 282
Ziggurat-style step-back 494
Zinc 281, 312
Zinc phosphating 348
Zinc plating 477
Zingiber officinale 155
Zion Canyon 276
Zirconium 310
Zona pellucida 606, 607
Zone
  Jupiter 44-45
  Structure of Saturn 47
Zone defenses 533
Zonular ligament 241
Zoom keys 590
Zoomorphic head 374
Zosteres 572
Zosterophyllum llanoveranum 64
Zubenelgenubi 18, 21
Zubeneschamali 18, 21
Zugon 373
Zygian 373
Zygomatic arch
  Bear 194
  Chimpanzee 202
  Human 215, 220
  Lion 194
  Smilodon 106
  Toxodon 107
Zygomatic bone 220-221
Zygomaticus major muscle 228-229
Zygote
  Bryophyte 118-119
  Fertilization 146-147
  Plant formation 146
  Primitive land plants 120
  Seaweed 116-117

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